Improvement of Operation Efficiency in Winnipeg Regional Health Authority (WRHA) Hemodialysis (HD) Units using Discrete-event Simulation Modeling

By
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Abstract

Facility based Hemodialysis (HD) treats over 75% of Canadian patients with kidney failure. HD in Winnipeg costs approximately $60,000 per patient annually and predictions indicate this population will double within the next 10 years. This research investigates workflow bottlenecks for improvement in HD units of Winnipeg Health Sciences Centre. A validated discrete-event simulation (DES) model is built as an efficient decision-making tool to evaluate different strategies in HD care processes for improvement based on proposed alternatives for renal program workflows. Simulation modeling is used to study the behaviour change of entities and resources in HD systems. Based on data of 2122 patient visits, proposed alternative scenarios in the simulation model examine key performance indicators (KPIs) including wait-time to start dialysis machines, length of stay, and percentage of times that dialysis machines start within the target time. The application of proposed improvement strategies results in desirable outcomes on KPIs up-to 31%. The solution can be applied to support future HD units' improvements.

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Dedications

This thesis is dedicated with love and affection to my dear parents, Hassan and Mahdieh, for their endless support and encouragement.

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List of Acronyms

HD	Hemodialysis
HSC	Health Sciences Centre
WRHA	Winnipeg Regional Health Authority
DES	Discrete-event Simulation
MRP	Manitoba Renal Program
CDU	Central Dialysis Unit
CKD	Chronic Kidney Disease - kidney damage for >3 months, with structural or functional abnormalities of the kidney
KARDEX	Generic term for certain centrally held storage-retrieval system for patient records. Originally a proprietary name for a filing system for nursing records and orders that was held centrally on the ward and contained all the nursing details and observations of patients that had been acquired during their stay in hospital.
PD	Peritoneal Dialysis
RHC	Renal Health Clinic

Chapter 1

Introduction

1.1 Background

Manitoba Provincial Dialysis Program was mandated by Manitoba Health in 1998 for dialysis treatments in Manitoba. In 2002, the program's name was converted into Manitoba Renal Program (MRP) to reveal the wider continuum of renal diseases under the umbrella of Winnipeg Regional Health Authority (WRHA) [1]. Patients with Chronic Kidney Disease (CKD) in Manitoba comprise a complex, heterogeneous population. The journey through the MRP is generally viewed as fragmented and frustrating to patients and providers alike. MRP provides the highest quality kidney care to patients with chronic kidney disease using an interdisciplinary team of healthcare professionals that include physicians, pharmacists, nurses, dietitians, and social workers. Kidney health clinics, kidney health outreach, and dialysis programs both at home and in hospital are considered as MRP's services for Manitobans.

To operate hemodialysis units, there are 20 locations across Manitoba including 4 urban and 16 rural and northern locations. MRP provides dialysis therapies for approximately 1200 patients, monitoring another 4000 patients through program's renal clinics. Moreover, in each year more than 275 Manitobans start dialysis treatment. Hemodialysis (HD) costs approximately $60,000 per patient each year. Based on prediction, this population will be doubled within the next 10 years [2].

Life-sustaining dialysis is required for patients with renal disease and kidney failure, these patients consume an inordinate amount of care resources and suffer from high morbidity and mortality. To improve health outcomes and reduce costs for this patient group, there are some evidence-informed interventions to be implemented. They include encouraging arteriovenous fistula use, enhancing transplantation rates, delaying the need for dialysis, long hemodialysis regimens, and the use of home dialysis modalities [3]. However, despite these measures, receiving thrice-weekly clinic-based HD is required for the majority of patients with renal diseases [4].

The effectiveness of implementing interventions for delivering better outcomes in healthcare at a lower price by dialysis providers has variability at international, national, and regional levels [5]. There are numerous reasons for such variability such as nephrologist preference, availability of expertise, and incentives structure. Furthermore, there is a big difference between health providers in terms of quality improvement, setting quality indicators and targets, data monitoring, collecting feedbacks, and using the aforementioned targets in the reimbursement process [3].

The ever-increasing number of dialysis patients results in many difficulties in health units due to insufficient resources [6]. In fact, the long waiting time is a common phenomenon in health-care systems. Waiting for care is the number one barrier in access to healthcare. To address such problems many research activities have been conducted to find efficient ways for improving patient care [7]. Improving the care quality has become even more challenging by recent reimbursement modifications approved by many insurers and governments. Such factors often result in bundling remuneration approaches and link payments to certain quality indicators [8]. However, HD units have opportunity for improvement. Dialysis units benefit from a complete control over resource allocation and internal processes. Therefore, the unit performance can be improved.

This research tries to achieve a balanced approach between delivering a high-quality care to the patients and efficient resource allocation. In this regard, literature is reviewed to reveal some contemporary concepts related to quality improvement for solutions to improve efficiency and quality of services in facility-based HD units. The goal is to deliver the efficient hemodialysis care with increasing number of patients, less waiting time, and reduced operating resources.

In several areas of healthcare systems, simulation modeling has been employed as an efficient decision-making tool for improving system performance such as forecasting, capacity planning, resource allocation, staffing and scheduling, measuring performance metrics, and supply chain management [9]. Using simulation, a replica of the real system can be built to investigate the process performance. It is particularly useful to detect bottlenecks of a system and study the effect of various process alternatives. In fact, before applying any prospective alternatives in an actual system, changes can be tested using the simulation model [10].

Different HD units serve for diverse kinds of population to provide care with different amount of resources and staffing. There is not a universal solution or process alternative to maximize efficiency, increase patient volumes and reduce operating resources while meeting patients and staffs' satisfaction. A simulation model can help analyzing and identifying different types of variability in HD.

1.2 Research Objectives

The objective of this thesis is to search solutions to improve the care performance of HD units using simulation modeling. A simulation model will be built based on the existing patient flow at Health Science Centre HD units in Winnipeg, Manitoba. The simulation model will be used to identify the care performance of the existing system and evaluate proposed improvement solutions. The simulation model will be run in different scenarios proposed to measure performances of investigated alternatives. Simulation results will then be presented to the MRP team in WRHA to evaluate proposed solutions for the overall service delivery and system throughput in HD care processes.

Following research activities are conducted in this research:

1. Data collection and analysis for activities in the existing HSC HD units to establish baseline of research,

2. Development of a validated simulation model to identify bottlenecks of the patient flow,
3. Design and test of alternatives to improve the identified bottlenecks,
4. Solution investigation using proposed improvement scenarios in the simulation model to achieve the improved operational efficiency.

1.3 Thesis overview

The thesis is organized as follows. Chapter 1 introduces the research background and objectives. Chapter 2 reviews literature conducted in HD units addressing difficulties for nurses and patients scheduling, improvement alternatives, and simulation modeling approaches and applications. Chapter 3 provides a description of the HD patient flow at HSC, HD teams and their workflows. Chapter 4 presents a general procedure of a simulation study and introduces different processes of the model development and details applied in the HD modeling for data analyzing, simulation modeling, and model verification and validation. Chapter 5 identifies bottlenecks in the existing HD patient flow and evaluates diverse improvement strategies and operating alternatives for the HD improvement. Chapter 6 presents thesis contributions, conclusions, and recommendations for future work.

Chapter 2

Literature Review

2.1 Hemodialysis

Kidneys help with filtering wastes and excessing fluids from the blood and expelling them though the urine. As kidneys' function degrades over time, it might cause chronic kidney disease (CKD). When kidneys' function becomes worse, they are not anymore capable of removing enough waste from the human body, which results in developing end stage renal disease (ESRD) [11]. Once a patient is diagnosed with ESRD, their kidneys' function is completely or almost completely failed and costly treatments like dialysis and often kidney transplantation are required for them [11]. In this regard, dialysis can be considered as an artificial replacement for the kidneys' function, which removes wastes, salt, and extra fluids from blood. Hemodialysis and peritoneal dialysis are two modalities applied in the dialysis treatment. In hemodialysis, the dialysis treatment is accomplished through the application of a dialysis machine that can be performed in special dialysis centers, hospitals, or at home [12]. To perform the hemodialysis treatment, doctors start with creating an access or entrance into patients' blood vessels. The access is then used to connect the patient to the dialysis machine and a dialyzer. Graft or AV graft, fistula or arteriovenous (AV fistula), and catheter or plastic tube are three types of access used for connecting patients to the dialysis machine. The first two types of access require a permanent access to the blood veins, which is achieved by a minor surgery and connecting an artery into the vein. Among these two permanent methods, fistulas are generally categorized as a safer access, which lasts longer [13]. Catheter access as the last method uses a temporary access that is inserted into the large veins like ones in the neck, chest, or leg. However, such temporary access is more prone to infections or causing clots [11, 14].

Before starting hemodialysis, two needles are used to connect patients to the machine, one for extracting and one for inserting the blood. With the commencement of dialysis, extracted blood coming out of patient's vein goes through a tube and passes over artificial kidney or dialyzer. The dialyzer filters and purifies blood at time using dialysate as a cleansing solution. Finally, another tube is used to transfer the treated blood to the patient [11-13]. A nephrologist assesses the health condition of a patient to set the duration of hemodialysis procedure accordingly. On average, a patient needs 9 to 12 hours dialysis per week, which is usually divided evenly between 3 or 4-time sessions [15]. The importance of right amount of dialysis is addressed in National Kidney Fund [12], which can improve the overall health condition of patients and enable them to avoid unnecessary hospitalization.

The annual care costs per person reported in USRDS is more than $70,000, ranging from $30,000 for transplantation to $82,000 for hemodialysis of patients [16]. As Knauf and Aronson claimed, the transplantation is a preferred treatment rather than dialysis due to lower costs [17]. However, such modality is very limited due to lack of sufficient organ donators. Similarly, hemodialysis is the most common treatment for ESRD in North America while the peritoneal dialysis is a cheaper approach. According to some studies, although the highest expenditure per ESRD is reported in North America, the poor health outcome results from the ESDR care compared to other countries [18]. Factors like lower reimbursement rates and enrollment of older and sicker patients in North America are among reasons for such phenomenon [19].

Besides the treatment approach, care providers (i.e. internists or nephrologists) may also affect the length-of-stay (LOS) and costs of ESRD patients. Studies conducted by Kshirsagar et al. show that non-specialist might not necessarily use fewer resources than specialists might [20]. According to the findings of this study, LOS and costs of hemodialysis under nephrologists' supervision is significantly lower than services provided by internists. Furthermore, difficulties in scheduling dialysis procedures may result in patients missing their appointments and more financial losses accordingly. Therefore, resolving difficulties that care providers are facing in HD units can improve the quality of healthcare services.

2.2 Difficulties for nurses in HD units

To improve the quality of services offered in dialysis units, providing nurses with better work environment becomes vital. Karkar et al. shows moderate levels of stress for nurses during working hours [21]. Such stress is mainly related to work overload with extra responsibilities, excessive number of patients, and longer working hours for treating sicker or older patients. The hemodialysis department personnel copes with additional types of stress, intensity of initiation and termination procedures, urgent interventions happening during life-threatening situations, and verbal and physical abuses during patients' treatment. Argentero et al. suggests three main categories for the physical or mental harms caused by overwork or stress as follows: emotional exhaustion, depersonalization, and reduced personal accomplishments [22]. Since patients have a strong emotional connection with their nurses, the emotional condition of nurses affects patients' satisfaction respectively. Such mutual interaction is observed where nurses' burnouts resulted in less satisfied patients [22]. Burnouts is a serious problem in hemodialysis centers. Numerous articles have tried to address this problem. According to findings when the ratio of patient to nurse increases, the possibility of burnouts augments [23]. A high risk of infections is another drawback of large patient-nurse ratio [24]. Furthermore, it can result in more distraction during the hand hygiene and more medication errors. However, factors like non-supportive environment and unfinished care tasks are found to be more important than the patient-to-nurse ratio [25]. Nevertheless, increasing the patient-to-nurse ratio is an unwise approach for improving the quality of healthcare services. The workloads among the care providers and rescheduling patients' appointments are applied more commonly in healthcare systems to improve the service quality.

2.3 Patient Scheduling

Before starting the dialysis procedure, some activities must be done as addressed by Holland [26]. As patients go through hemodialysis three times per week with approximately the same duration of treatment, it can be considered as a unique case for planning and scheduling. Patients' arrival at the same time at the dialysis center is the main bottleneck as reported by Holland. The main downsides arising from such scheduling are underutilization of dialyzers, patients queuing, and limited appointment options for new patients. As a solution for rescheduling the patients, Holland has suggested 15-minutes time intervals for patients' arrival. This approach has resulted in reduced waiting times for patients. Absenteeism with such approach means automatically reduced waiting time, higher degree of utilization of dialysis machines, and reduced operating hours in general.

There are few studies conducted on patient scheduling in hemodialysis units. However, patients scheduling in general is well addressed by many researchers. Generally, research in this area can be classified into two categories: static and dynamic appointment systems [27]. In the first category, the appointment system is a static one. All decisions are made in advance and there will be no uncertainty assumed in the system. Therefore, modeling such system becomes an easy task which makes it the most popular scheduling approach. On the other hand, in the dynamic system, schedule is revised continuously throughout the day. The simplest implementation for such scheduling happens when all patients arrive on time and only one doctor is present. In this case, stochastic processing times are applied in modeling. Such model might become more complicated due to increasing number of services, doctors, and appointments per session in the unit. The level of complexity increases even further by considering details like uncertainty in arrival times, service time distributions, queue disciplines, and lateness and interruption of doctors.

2.4 Research Motivation

The regular presence of dialysis patients and imposing expenditures on healthcare systems are among the main concerns of hospitals and dialysis units. To cope with the prevalence of dialysis patients and complications of the treatment, strategies are required for planning the capacity and quality of healthcare services offered by hospitals and dialysis units [17, 26]. Building new dialysis centers, increasing the capacity of dialysis units with more stations, and extending operating hours of present units are among many solutions for improving the capacity of dialysis services. The main obstacle against such solutions is the high expenditure required for their application. This study focuses on rescheduling and modifying the present patient flow as an economic solution for improving the unit's capacity by utilizing the existing resources efficiently.

Addressing patients' needs on a daily basis might result in extended LOS. When the inpatients demand is high, scheduling their dialysis besides accommodating other scheduled procedures becomes challenging, which can lead to longer stays. According to Forrest et al., performing all the procedures based on plans results in minimized LOS for dialysis patients [28]. To investigate such strategies, building an accurate simulation model of the healthcare system becomes an inevitable step.

2.5 Simulation Modeling of Healthcare Systems

There are various fields using simulation modeling successfully such as manufacturing industries, service industries, finance and training [29]. It is more than four decades that operation research has been applied to the domain of healthcare. Using operation research models results in assisting clinical decision making, resources allocation, facility location and planning, organizational redesign and evaluation of treatments. One of the most popular used operation research methods is simulation as a feasible technique for the healthcare improvement [30]. As healthcare systems are uncertain and variable, healthcare simulation modeling would be very complicated. A stochastic modeling approach is required for healthcare systems to deal with the complexity. The communication and interaction are needed between the model and users [31].

Evaluation and improvement of existing resources and processes are objectives using simulation modeling for healthcare systems. Systems analysis tools play a major role in this process. In order to examine different scenarios, assumptions, policies, and re-engineering ideas, simulation-based methods have been employed as an essential tool for the system analysis.

Discrete-event [32], system dynamics [33], conceptual [34] and mathematical modeling [35] methods have been used as various modeling techniques in studies. In most cases, the stochastic system is used to model HDs.

2.6 Simulation Approaches

There are three simulation approaches mainly used for the healthcare system: discrete-event simulation (DES), system dynamics (SD), and agent-based simulation modeling (ABSM) [36]. DES as an essential tool is used where an operational understanding of a system is required. SD as a strategic tool is used at a high description level to demonstrate the system's behaviour [37]. ABSM is a methodology to understand the impact of human factors in system operations [36].

Entities in the DES models are described as passive objectives [36]. Interactions between entities and related characteristics selected from the target system are investigated using DES models. In addition, massive data collections are required for the model development that could be considered as the challenge of DES applications. Many researchers have used DES models to find the optimal resource mix or staffing schedule [38].

The discrete system is predominantly considered to model the HD. To evaluate allocation of resources and patient flows in HDs, DES as the most popularly decision support and operations research tool has played an important role [30]. One of the DES models is a queuing model used to demonstrate patients queuing to have accessibility to available resources. For instance, Yilmaz et al [39] employed the queuing theory in evaluating different scenarios in order to gain an optimal number of resources to maximize the level of a unit service. This theory seems to have an immense value in finding an optimal solution.

To schedule patients and evaluate appointments policies, simulation-based methods have been widely implemented. For example, in order to schedule patients to minimize delays in treatments and maintain efficient use of capacity, Olugata et al. used the slack capacity approach in a radiation oncology department [40]. In this regard, using a dynamic DES as the most appropriate tool, some patient capacity was reserved as slack capacity. Olugata et al. perceived that in case of a high patient frequency, the slack capacity is the main reason for treatment delays to cause inefficiency in the system. Further, they analyzed that patient arriving frequency has a high effect on the normal capacity usage ratio.

There is a variety of DES modeling tools including Arena, SIMAN, MedModel, and Simul8. In addition, some of them are written in SLAM (Simulation Language for Alternative Modeling) [10]. In this research, the simulation software tool, Witness 14.0, is used to model the general patient flow and HD processes of system operations.

The second simulation approach is System Dynamics (SD) represented by differential equations. SD using mathematical models is made up of different state variables and diverse algebraic equations with numerical inputs [36]. In these models, to represent target systems' actual components such as location and concentration, integrated variables are used. Considering the qualitative aspect of SD, the simulation modeling puts emphasis on actions' unintended consequences [7]. Although SD models are able to run fast without requiring multiple replications, misleading the conclusion caused by ignoring system stochasticity is the potential risk of SD modeling.

A relatively new approach is agent-based modeling and simulation (ABMS) that uses autonomous and interacting agents [41]. Using agents in ABMS models, external requests would be responded, and even simple plans are made in the system.

2.7 Applications of the Simulation Modeling

In healthcare systems, simulation is a very useful tool to help achieving various objectives for improvement. Based on several studies, there is a variety of organizational benefits and cost savings in hospitals planning and scheduling by using simulation [30]. Furthermore, the operational process flow of specific healthcare delivery units is assessed in some simulation studies. To analyze what-if scenarios, simulation is capable to allow a remarkable exploration of different options with very low expenses on staffing, training and equipment [42]. DES as an effective tool is used for operational analysis of stochastic processes of the healthcare delivery [43]. DES is helpful to model various real-world problems where other types of analytical techniques cannot provide solutions. Various specialized applications of healthcare units using simulation are well documented [44]. A key factor for using simulation in healthcare systems is insignificant physical investment and lower risk to test alternative scenarios of changes in process flows and resource locations [45]. Examples of simulation applications in healthcare include a DES model to analyze the renal transplant for decreasing the waiting list [46]; a simulation model of outpatient clinic scheduling systems considering scheduling algorithms, patient flow logics, external demand for appointments and supply of provider timeslots [47]; a simulation model of a hospital layout for using resources efficiently [48]; an emergency department's simulation model to improve patient flows and reduce waiting time [49]; a simulation model of the emergency room in a hospital to analyze the maximum level of demand and required resources with minimizing the need of facilities and human resources required to serve demands [50]; a simulation model of an emergency care centre to analyze the detailed process in the system [51]; and a simulation model of a medical center to make necessary changes on patient flows to reduce the length of stay [52].

Several simulation software tools have built-in experimenters to test a variety of scenarios such as the OptQuest tool in Arena that can use different meta-heuristics such as SS, TS and neural networks. For example, a model was built based on a developed model for diabetic retinopathy [53]. The developed model was used to simulate effects of various screening strategies on diabetic patients and to compare them in terms of two objective functions. To make policy recommendations, results were presented in the model for a range of different scenarios. Witness software has a tool called Experimenter including different algorithms such as Adaptive Thermo-statistical SA, Hill Climb, Six Sigma and Random Solutions [54]. A variety of scenarios can be tested using this Experimenter for improvements.

Modeling human behaviour as entities in simulation models of healthcare systems is much more complex than modeling materials as entities in production industries. Modeling human behaviour is not limited to healthcare systems. In manufacturing industries, modeling workers behaviour is substantial [55]. In fact, human behavior has a high impact on system outcomes in practice. There are various studies analyzed models of health-related behaviour such as a DES model that combined the Health Belief model with PECS (an approach which considers the physical, emotional, cognitive and social aspects of human behaviour) to provide a model of attendance for diabetic retinopathy screening [56], and a Theory of Planned Behavior for analyzing woman's attendance in mammography of breast cancer screening [57].

Developing a DES model of the targeted healthcare system opens up improvement opportunities by modifying the current workflow. Among various improvement strategies, float nurse and staggered start time approaches are mainly applied to improve the performance of the HD unit model in this research. Before implementing such improvement alternatives, further research is required.

A simulation model of a healthcare system in [58] was developed to improve the LOS. A noticeable reduction in LOS is achieved by introducing a float nurse into the system. The float nurse is applied to take over duties of the responsible nurse while he/she is busy. Furthermore, nurse jobs are reassigned by considering the float nurse as a primary one. This can lead to longer working hours for the float nurse, which overshadows its benefits. Another study in a community hospital of Lexington was proposed for work sharing as a nurse floating policy [59]. During busy hours, the float nurse will join the responsible nurse to share duties. However, such approach has not shown a remarkable level of improvement in reducing LOS. A broader study was conducted on 400 beds using simulation modeling in Midwestern Veterans

Administration (VA) hospital to modify working hours of nurses. Results illustrates that unrestricted nurse floating in comparison with cluster nurse floating produces significantly fewer understaffed shifts. However, the latter approach provides a better oriented staff at the cost of less absolute availability in hours of nursing care [60].

Staggered start time as another improvement strategy was applied in endoscopy unit at Duke University Medical Center using simulation modeling in Simio® Simulation Software (Simio LLC) platform [61]. A DES model was applied to evaluate alternative staffing models and patient schedules to improve unit efficiency. Staggering nurse schedules rather than staggering appointment schedules resulted in more decrement in overtime shifts. Unlike the previous study, Azraii et al put the emphasis on staggering the appointments to decrease the waiting and consultation time, following up with patients, and improving the queuing system for walk-in patients [62]. Jun et al shifted the emphasis from a single block scheduling system to staggered block scheduling one in an outpatient clinic. This resulted in reduced patient's waiting time with no decrement in utilization of physicians [63].

According to the present literature, there are few simulation modeling-based studies applying either staggered start time or float nurse as improvement strategies. Furthermore, there is a lack of studies conducted to improve efficiency in HD units using such alternative solutions. This research is an attempt to fill the gap between improvement strategies and simulation modeling in HD units.

2.8 Summary

Nurses difficulties in HD units and patient scheduling are main concerns of the HD system. Such problems have imposed a large expenditure on HD units' operations. Simulation modeling can be used for depicting the operation processing and evaluating possible alternatives such as float nurses and staggered start time strategies resulting in reduction of patients' LOS and improvement of HD operations. Despite the fact that using simulation is a well-established process in healthcare systems, very few studies were found to address improvement of operation efficiency in HD units using simulation modeling.

Chapter 3

WRHA Hemodialysis Units

This chapter introduces the HSC HD. A general overview of the HD is presented in the first section. The second section provides the detailed patient flow in the HD. The third section presents the problem statement formulation.

3.1 HD Treatment Units

Hemodialysis Unit (HD) at Health Science Center (HSC) is an ambulatory care clinic to treat both inpatients and outpatients who suffer from the chronic kidney disease. The HD at HSC began processing chronic hemodialysis patients. Over time, as this unit has grown and matured, co-morbidity has added including more inpatients. A number of acute patients brings a high workload and increased burden of social issues.

There are different items in an individual program such as the length of treatment, frequency of treatments and composition of the dialysis solution along with flow rates and size of dialyzer. Based on patients' bloodwork and size, nephrologist prescribes a treatment program. For each patient, the conventional hemodialysis is operated three times per week for about 3 to 4 hours per treatment. The patient is closely monitored during the treatment.

For dialysis, a vascular access to patient's blood is required. A Central Venous Catheter (CVC) or an Arteriovenous Fistula (AVF) is used for HSC HD patients. The patient's treatment program or time of dialysis is different based on the type of access used.

Currently at HSC, HD is operated in three separate areas labeled Unit A, Unit B and Unit G. In this research, Units A and B are considered. Unit A has 25 beds and Unit B consists of 11 beds. There are 4 beds in Unit A and one bed in Unit B used as isolated beds. Units A and B are addressed and staffed as single sections. However, there is only one waiting room for both units. Together they service 108 patients per day.

In addition, there are 41 dialysis machines for 36 beds in Units A and B, five machines are for backup. Sometimes some of these backup machines are needed for the Home Hemodialysis (HH) program, which can pose a risk if machines fail in the units. Figure 3-1 shows the HD layout.

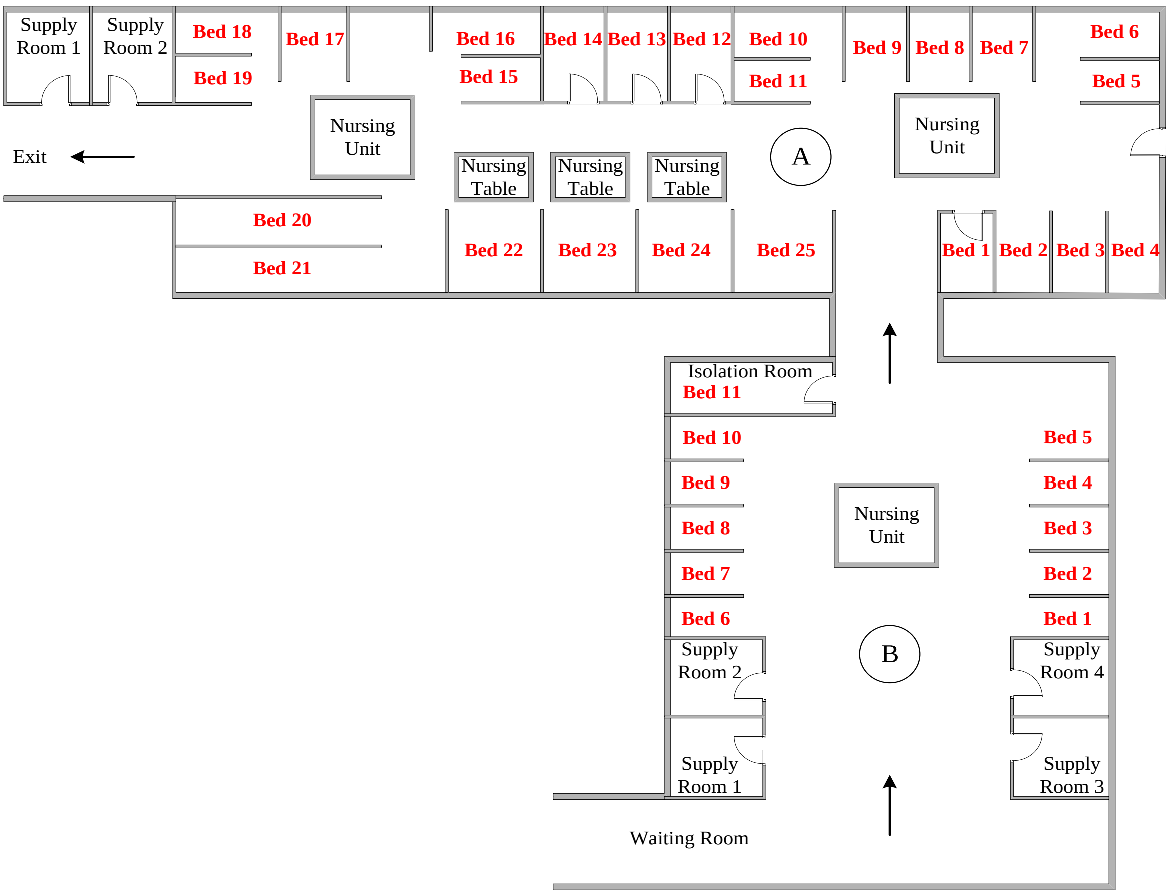

Figure 3-1 A simplified HSC HD floor plan

3.2 HD Patient Flow

3.2.1 Scheduling System

HD Units are resource-based rather than patient centric operations, which is dependant on availability of the staff, bed/station, and dialysis machine. Consequently, the patient flow and operation scheduling are mainly based on resources, not based on the patient need.

A set of schedules is created by the Clinical Resource Nurse (CRN) to assign patients to specific beds to dialyze. In order to keep the patient flow moving smoothly, the schedule is adjusted all the time. For example, rescheduling an inpatient who is available 24/7 is easier than an outpatient. However, inpatients may not receive a scheduled dialysis if there are several unscheduled/new outpatients in a day. As a result, there is a need to transfer patients from their rooms to HD units and back more than once per day to check the availability of beds.

There are four flex spots used in scheduling for movement, such as rescheduling accommodating inpatients from ER or other local centres for surgeries, and processing HH patients with machine problems or other complications.

In addition to above-mentioned issues, sometimes a scheduled bed may become unsettled leading to health/safety issues, which is caused by the HD delay in the dialysis setup or process. For example, if a patient starts late for the scheduled time, his/her dialysis cycle may be shortened to meet the transit time or next appointment. Therefore, the patient would experience an unpredictable and stressful situation. The longer dialysis time would be required for the next scheduled treatment, which creates a rescheduling issue.

Moreover, due to transit issues, time gaps can be created. A patient may arrive late to the unit for the case due to transportation delay. The outpatient may then need to be re-scheduled. In addition, the HD nurse training course is a formal training program that includes four weeks of clinical practice where nurses go through procedures line by line. Since the trainees are likely working slower than experienced nurses, this process impacts the patient flow and scheduling in HD units. As a final point, many times, a scheduled patient does not show up for dialysis. The settled bed is not being used if the CRN is unable to request another patient to come in on such a short notice. There may not be any inpatients to use this bed either. In this case, an open bed that is not used will cost approximately $300 for the set up and solution.

3.2.2 Input-Throughput-Output Phases

There are three phases for patients' journey from arrival to discharge: Input phase, Throughput phase and Output phase.

Input phase of patient's journey begins when a patient arrives at HSC and enters the HD for dialysis. The patient waits in the waiting room until a Health Care Aides (HCA), Transport Assistant (TA), or a volunteer advises the patient the station (bed/chair) is ready. At this point, the patient weighs himself/herself in the unit. One HCA helps the patient if a Hoyer is needed for the patient to weigh and get into the bed. Hoyer lifts are used for transferring patients with a minimum physical effort. The HCA records patient's temperature and then assists the patient to the assigned station. As soon as the patient is assigned the bed/chair, the nurse completes a patient assessment including blood pressure, diet, weight, and other health conditions, determines the amount of fluid removal required, and starts the dialysis machine to begin the dialysis treatment.

The throughput phase is from the dialysis machine start to the treatment completion. In this phase, while the patient is dialyzing, the nurse monitors the progress (approximately every 30 minutes) and provides a variety of treatments if needed.

Pharmacist, dietician or nephrologist may also use this time for care discussions directly with the patient. Dialysis treatment can be a 3 to 5-hour cycle with the longest cycle prioritized first. A patient is prioritized by the length of cycle time, and/or other issues that need attention. Also, as some patients have other appointments before or after the dialysis treatment, i.e. there may be an appointment for chest x-ray, or problems with breathing or other health conditions, these patients are put in the priority sequence.

Once the dialysis treatment is completed, it is the output phase of patient's journey. A nurse takes the patient off the machine, rinses the tubing and performs reassessment, weighs the patient, and assists the patient back to the waiting room for travel arrangements. The patient flow is shown in Figure 3-2.

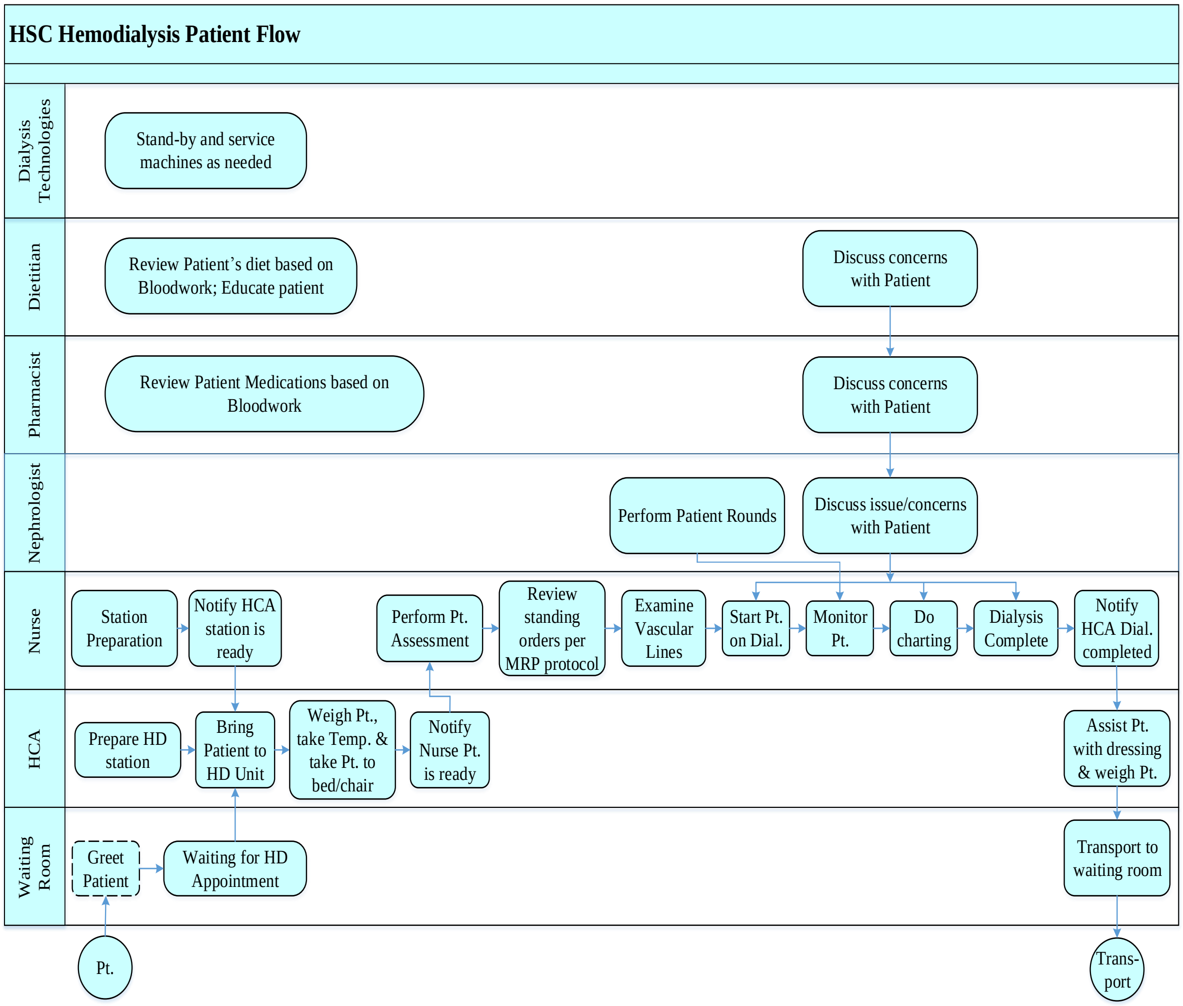

Figure 3-2 A general patient flow in the HD

3.3 Hemodialysis Team and Workflows

HSC HD uses the interdisciplinary team approach for patient cares. The interdisciplinary team includes nephrologists, unit clerks, Health Care Aides (HCA), nurses (RNs, LPNs, Clinical Resource Nurses (CRN), nurse educators), transport assistant (TA), dialysis technologists, dieticians and pharmacists. There is not a standard operating procedure or task identified for a specific role or level of competency for team members.

3.3.1 Nephrologist

There are total 9 nephrologists for dialysis at HSC HD. 5 nephrologists are on some rotation at one time. There is 1 nephrologist assigned to Unit A, and 1 nephrologist assigned to Unit B. However, they also cover a number of other HD units in the hospital (GG7 – 5 patients per shift; PHDU – 8 patients per shift only in afternoons; 5 local centre HD units – phone rounds done weekly on each unit to deal with any phone calls and problems). Moreover, the inpatient nephrologist takes care of any HD patient admitted to hospital and is responsible for these patients. In addition, the consult nephrologist is responsible for any new patients admitted to HSC who have started dialysis. In total, there are at least 3, maybe 4 nephrologists who see patients on HD.

Based on nephrologists' schedule, morning and mid-day patients are seen at least once per week on either Mondays or Tuesdays (i.e. Monday, Wednesday and Friday cycles are seen on Mondays; Tuesday, Thursday and Saturday cycles are seen on Tuesdays). Evening patients are seen at least every 2 weeks. However, it may happen more frequently if there are ongoing problems. Evening rounds are usually Monday and Tuesday evenings, but again it depends on nephrologists' schedule. Nephrologists are responsible for giving charge nurses their rounding/availability schedule at the beginning of each week.

3.3.2 Unit Clerk

Administrative responsibilities of units are operated by unit clerks such as; preparing new patient files and/or the file conversion for HD Unit as well as providing all patient requisitions and transcription of physicians' orders. Moreover, unit clerks are responsible for patient appointments for tests, setting OR slates and ensuring completed pre-operative testing to be forwarded with packages to the OR.

There are five unit clerks providing service for 36 beds in HD units. Three clerks work an 8-hour shift in alternative day/evening, and there are two 8-hour fulltime evening shift. They mostly work between both units based on the need and workload generated, i.e. if the transcription from one unit is too much to be handled by the unit clerk to cover a unit, the second clerk will be added.

For a patient that is a new start or conversion, the unit clerk ensures that the patient's file is prepared for the HD unit with a different Medical Admin Record (MAR) to include all necessary forms and medical sheets. Hospital Registration will be notified if the patient changes to modality to ensure that the file has a new addressograph card and admission sheet from Hospital Registration.

In addition, HD registration requires any new patient to have an initial bloodwork per MRP protocols to identify what needs to be flagged (i.e. Diabetes tests, CBCs, etc.). The unit clerk will prepare requisitions to make appropriate appointments for the patient. In fact, the unit clerk prepares all requisitions for all patients, including monthly bloodwork, chest x-rays, EKG, and MRSA surveillance. Monthly bloodwork is done in HD units, 2 times in each month for all patients. Nurses draw the blood on Wednesday and Thursday cycles. The unit clerk will then generate the lab flow sheets on Fridays and Saturdays for distribution and review by pharmacists and dietitians. Nephrologists review and sign-off (write orders) after pharmacists and dietitians.

Moreover, the unit clerk transcribes orders to Medical Flow Sheets and Medical Admin Records (MAR). Physician orders are transcribed for sign-off, and then the standing medical orders are transcribed for nurses.

Unit clerks are also responsible for collecting and forwarding statistical data. Weekly patient statistics are forwarded to Registration (i.e. any permanent movement, patient demise, transfers to renal health clinic). Daily stats are collected from nurses and are entered a billing spreadsheet.

Hepatitis A&B and HCV vaccines are required for all renal patients, which is tracked by unit clerks. To determine what vaccines are required, patient charts are reviewed for vaccination history per MRP protocols. Vaccinations are done by the RN and then on initial vaccinations, nephrologist will sign-off to have an up-to-date vaccination record.

3.3.3 Health Care Aid (HCA)

HCA assists with the assigned patient care and maintenance of a safe clean environment in HD Unit. Units A and B have six HCAs while each HCA works an 8-hour shift. There are two shifts per day, Monday through Friday.

Six HCAs begin at 6:30 AM. Four HCAs is scheduled to turn on water and Bicarb System, and also set up the dialyzer on 26 dialysis machines in Unit A. Two HCAs completes set-up on 11 dialysis machines in Unit B. In the morning, 5 minutes is needed per machine for this initial setup.

When a nurse is ready for patients, HCA is advised to the waiting room for bringing a patient to the Unit. The HCA will then help the patient to weigh if needed, take temperature, and escort the patient to the assigned bed. In some cases, a Hoyer is required to lift the patient to weigh and place in the bed before dialyzing if a patient is non-ambulatory. At least 2 staffs are required for assistance in this process, which may take more time. Regarding this, knowing the type of the scheduled patient is helpful for staffs to prepare special needs in advance.

During the dialysis, cleaning stations (plastic wraps, debris), providing warm blankets, ice water, stocking supplies and generally making the patient comfortable are considered as HCAs' responsibilities. They are also busy setting up a patient cart for the next shift. Required supplies for the next group of patients, along with patient Kardex and patient information are included in the cart.

Finally, when the dialysis treatment is completed, the nurse and HCAs will be advised, and all the used supplies will be stripped off the machine by the HCA. Furthermore, the HCA puts the machine into a 20-minute rinse, wipes down the machine and patient table, and sets up tubing and solution for the next patient. After the last assessment by the nurse, the HCA will weigh the patient and assist him/her to the waiting room, if needed.

3.3.4 Nurse

There are full-time nurses trained specifically in dialysis in HSC HD Units. Registered Nurses (RN) and Licensed Practical Nurses (LPN), with no distinction between roles/responsibilities, are members of the group. However, the HD Unit Charge Nurse must be an RN. Based on the beds structure, nursing staff have their own scheduled hours. A ratio of nurse to patient is 2:1 throughout the day. Patient changeovers happen at 8:00 am, 1:00 pm, and 6:00 pm, which requires complete nurse/staffing in a day.

In addition, nurses use a paper-based system for the patient charting manually. Monthly charting includes vascular access tests and notes along with updated monthly Lab Flow Sheets for all trends. As a matter of fact, patients' locations and charts should be at the same HD unit. There are several binders retained in HD units with all scheduled HD patients' information. Also, for every patient, Treatment Flow sheets on every visit and Wound Assessment sheets for each wound treatment should be completed by nurses while foot assessments are done for diabetics once a week or once a month.

Programing dialysis machines, checking prescriptions, testing equipment and running the dialyzer and tubes are essential processes before a patient is shown to his/her dialysis station, which are done by nurses. While the dialysis machine is being programmed, the nurse reviews the patient chart, writes on the Treatment sheet (if not previously set up), and then gets medications and syringes ready for that patient. Altogether, the full process takes approximately 30-40 minutes for each patient before dialyzing.

As it was previously stated, after patient's arrival to the unit and getting weighed, the nurse completes an assessment including the blood pressure, diet, weight, and other health conditions. Then, the patient discusses any concern with a nurse and the nurse determines if any bloodwork is needed and how much fluid needs to be taken off. Providing that, the machine will be ready for the patient without problems with vascular access or lines. However, there are problems with vascular access approximately 1 in 5 times, which causes 20 to 40 minutes delay in the treatment.

In every 30 minutes, nurses monitor patients dialyzing and complete charts for the patients, do wound care with patients if needed, dress for central lines, consult with other disciplines, and prepare medications. Meanwhile, charts are also prepared for the next group of patients. Distributing some medications after the dialysis such as antibiotics or iron would extend the use of the bed to 30 minutes or more.

Nephrologists provide the order of medications for each patient. There are protocols to follow in order to adjust medications on machines depending on the bloodwork. If the mix is not right for the patient, the nurse will add chemicals (i.e. extra calcium powder). If a machine is not programmed for that bath, the nurse may need a different machine and re-start the setup. These extra processes would take more time.

In addition, 2 days of every month are scheduled for monthly bloodwork for each patient in HD units. Drawing the blood and proper labeling of everything are nurses' responsibilities. As a result, approximately 10 minutes are added to each patient's time in the bed. On the other hand, in some cases, the treatment should stop by a nurse to collect a blood culture during dialysis, flush the central line and take blood from the line as well as a second location on the arm. Once completed, the nurse scrubs the line and re-hook up the patient, which results in approximately 10 to 15 minutes added time to the process.

As the treatment is done for a patient, another assessment will be performed by the nurse, the nurse rinses tubes and takes the patient off the dialysis machine, which takes 15 minutes for each patient. Although more time is needed for some patients (patient's first treatment, or inpatient or acute patient), there is not any unique scheduling for them. Moreover, more time is required for patients in isolation due to setting up screens and different nurses' workflows for security reasons. For this case, the added time required will impact the bed scheduling and next patient's timing.

3.3.4.1. Clinical Resource Nurse (CRN)

Resources to patients, patients' family, nephrologist, unit staff and allied health team are Clinical Resource Nurses (CRN) who are named as "Go-To" people in HD Units. HSC has 4 CRNs covering both HD Units A and B. In a rotating cycle, three of the 4 CRNs are scheduled working every day. Their shifts/hours are changed in following weeks. Such work sharing scenario of CRNs results in 4 different categories: working in permanent schedules, working rounds, being a resource, and working on changes. For example:

- CRN1 works an 8-hour evening shift Monday to Friday with a focus on assignments and scheduling staff;
- CRN2 works 3 12-hour shifts Monday to Wednesday with a focus on resources;

- CRN 3 has 4 shifts, working 3 12-hour shifts Wednesday to Friday and one Saturday 8-hour shift for rounds;
- CRN4 works an 8-hour day shift Monday to Friday with a focus on assignments/changes.

Their duties will be rotated among them in following weeks. On unit B, one CRN is assigned to flow who works on the permanent and temporary schedules, as well as dealing with day to day capacity issues. The second CRN in unit B is assigned to clinical issues who does rounds with the physician, acts as a clinical support to the nursing staff. On unit A, the CRN is clinical, and communicates with the Flow CRN regarding schedule changes.

In fact, managing HD units is considered as the main responsibility of CRNs. They conduct a variety of services for the treatment process such as triage, trouble shooting and main intervention before calling a nephrologist. Theoretically, they spend 90% of time dealing with current issues, and remaining time for patients or staffs' scheduling. CRNs' duties are explained as follows.

Assigning patients to beds and scheduling of nurses and HCAs in the HD units are considered as CRNs' responsibilities that ensure each station team setting up appropriately (i.e. a senior nurse matches with a junior nurse; RN with LPN) and the patient load is divided equitably amongst the Treatment Teams and amongst both HD Units. Moreover, CRNs ensure all staff is replaced if they call in sick. They also take the patient assignments when staff call in sick and cannot be replaced.

The access type developed is for CRNs to schedule patients. If it is a patient's first dialysis treatment, in order to provide the access type, it takes approximately 1 hour for CRNs to set up. As scheduling is currently a paper-based system, the CRN adds the patient information to an Excel spreadsheet for scheduling that includes patients' cycle days, best time of day, if outpatient, ISO or inpatient information. There are two types of patient scheduling: permanent and weekly schedules, taking approximately 2 hours.

In addition, main resources to HD nurses are CRNs, which is the reason for acute care patients to be assigned to beds closely to CRNs' workstations. For example, CRNs needle the difficult fistulas. Even in some cases, a lot of external communication is needed for a patient to transfer to another facility for vascular intervention or creation done by CRNs. CRNs track patient census such as transfers, admissions, discharges, and deaths. Moreover, as the education of nurses and patients is a big part of the CRNs role, CRNs spend a great amount of time for staff teaching new protocols and mentoring nurses and support staff. They are also required to troubleshoot any machine issues in evenings when technologists are not available.

Prioritizing and coordinating the intake of patients are conducted by CRNs. For example, CRNs decide the placement in HD units for patients who should wait in the ER to dialyze. Sometimes patients are moved from the renal clinics or another facility and then they need to be registered and scheduled. They also coordinate the intake of HH patients if there is a machine failure. In addition, completing paperwork, answering resource questions, and documenting stats are conducted by CRNs in their downtime.

Rounds Books, paper-based systems, are used for documenting patient summaries and reporting current issues completed by CRNs. It is updated as issues occur, and results of tests and consults are available, to ensure all information is current and timely for patient Care Plans. Afterward, information from Rounds Books is entered into an Excel spreadsheet.

3.3.4.2. Nurse Educator

There are four nurse educators working in day shifts in HSC HD units, Monday through Friday. They are not directly involved in patient cares; however, their role has indirect patient care responsibility via staff's contact during training. Although education and training of nurses, HCAs and auxiliary staff are the priority of nurse educators, other hospital related responsibilities such as orientations and new health care initiatives would be considered as their duties as well. Additionally, for experienced staff with questions relevant to patient care, nurse educators have responsibilities for helping as well as for a nursing assignment if needed, in both working hours and overtime. In fact, the last resource for the CRN's scheduling is nurse educators.

There is a formal 9 weeks training course for HD nurses (6 weeks clinical based learning and 3 weeks of preceptorship), which is scheduled for six times a year with approximately 1 to 5 students per class. Clinical practices with a patient would be completed by students. Providing that, they go through procedures line-by-line, which would impact patient flows and scheduling in HD Units (i.e. students would be slower than experienced staff). To schedule students in the units, the educators work with CRNs.

CRNs try to get patients with the same cycle time and group them in the same bed structure (as close together as possible) while the selected patients are more tolerant among others and understanding the process better. To investigate the maximum students' ratios, monthly meetings are arranged with educators, managers and directors.

3.3.5 Transport Assistant (TA)

There are Transport Assistants (TA) working Monday through Friday in HSC HD units. Not only the transport of inpatients and ER patients to HD Units are considered as TA's responsibilities, they are responsible for assisting the HCA with transporting patients as well.

More time may be required for inpatients for their scheduled time in HD, since they may not be ready for pick-up/transport. Therefore, a time saving approach must be applied. For this reason, the TA is expected to inform the area nurse about moving the patient and to ensure the patient readiness. Furthermore, the TA checks stretcher or wheelchair requirements. The TA contacts the area nurse once again to inform them about returning the patient. Besides such time saving duties, TA can help the HCA with weighing patients, taking their temperature, and assisting them to the bedside. At the end, a TA may also take the inpatients back to their room, if an assigned bed is needed for an ER patient.

3.3.6 Dialysis Technologist

Dialysis technologists are not directly involved in the patient care. Their duties are mainly focused on technical sides of the HD team/program. Ensuring patient dialysis machines working and medical equipment safe and maintained according to standards can be considered as their main duties. All in all, there are assigned dialysis technologists at HSC who work in an eight-hour shift.

Nurses are supposed to notify dialysis technologists for their immediate assistance when the HD equipment is not working properly. If patient's dialysis is interrupted by up to 20 minutes, the whole machine will be replaced with a new one. All HD units' machines are checked monthly along with microbiology samples. HH equipment is also a part of dialysis technologist's duties.

At the moment, there are 41 machines for 36 beds in HD units among which 5 machines are used as backup. However, one machine may be used for the HH program, which deteriorates reliability of the unit. The dialysis machines are supposed to be upgraded by the end of this year.

3.3.7 Dietitian

Dietitians work on their own individual schedule and their own days; however, they share all patient data, including clinics and patient files. Consequently, they maintain accurate notes on their patient files using a standard Nutrition Care Plan forms and Progress Notes form that can be shared. These completed forms are not kept in the HD patient charts rather in the dietitian's own patient files. Transcribing is then required when the dietitian leaves a note in the Patient's Chart.

Dietitians are advised for an HD starting from Clinics (RHC or PD), from weekly rounds, or from another facility if the patient is being transferred in. If the patient is a transfer-in, the other dietitians may fax the progress notes/files to facilitate the start of a patient file at HSC.

Once the patient is in the HSC HD Unit, dietitians will review the chart and determine if diet teaching is required. If this is an evening patient, the dietitian will phone and leave information in the patient chart for picking-up. Dietitians will try to meet new patients in the HD Unit during treatment (due to a lack of the space to meet off the HD Unit).

The dietitians use a paper-based communications book to leave messages for themselves, and they use physician's communication books to leave messages for nephrologists. Monthly stats are kept on their work load measurements to identify the amount of patient activities, non-patient activity, and in-patient activity during a month. Dietitians also perform monthly and annual reviews including bloodwork, medications, and weight changes. All issues that have arisen are discussed with the patient.

3.3.8 Pharmacists

Despite the fact that pharmacists are present at Hemodialysis Unit every day, they may not necessarily get involved within patients' treatment. A direct interaction with patients depends on their specific daily needs.

Arranging the time schedule of pharmacists is done by the head of HSC pharmacy and they are hired by WRHA. Their work in the renal program is contract-based. Med-reconciliations, tracking patients' hemoglobin, and reviewing several medications can be duties of the pharmacists. Medication review starts with a full review for newly admitted patients to the system and will end up with medication reconciliation on their discharge. Furthermore, there will be an annual medication review being conducted for all HD patients. As an outcome of such review, patient charts will be updated by common drug problems.

Chapter 4

Development of Simulation Model

This chapter is dedicated to development of the HSC HD simulation model. It is divided into three sections. In the first section, DES study and Witness software used to build the model are briefly introduced. The second section explains the model building methodology. The third section introduces the model input data, verification and validation of the HSC HD simulation model.

4.1 General Procedure of the DES Model Development

Objectives of building the simulation model are evaluation of the HSC HD performance, improvement of using medical resources, and examination of workflows and operation processes in HD units to maximize the quality and efficient care. A conceptual model is proposed based on operations of the target system, HD units, to demonstrate the whole patient/staff flows. Converting gathered data into a form of distribution functions is conducted in the simulation modeling to depict characteristics of the system operation.

Generally, there are several steps to conduct a DES simulation study including formulating the problem, defining study objectives, developing a conceptual model, collecting data, designing and building model, verifying and validating model, searching solutions through analyzing the model, and forming documentation. A DES modeling procedure is shown in Figure 4-1. Understating the HD function is the first step to build the model. One can formulate the problem statement based on HD understanding. It not only identifies problems to be solved but describes an overall aim of the project with the project restriction. A conceptual model is developed with essential features of the HD system for objectives of the simulation study. In the conceptual model, there are some assumptions to simplify the modeling effort. To simulate HD operations, the conceptual model has to be transformed into a data-driven computer programmed model.

The simulation model is built by following a variety of elements in HSC HD units including patients, HD staff, service operations and patient flows. The model uses elements to represent physical components such as resources, flow lines, and infrastructure [54]. The level of details of model elements is mainly dependent on the system nature and modeling objectives. The layout, structure, logic, data and statistics of the HD units are built in the DES model.

During the simulation modeling process, verification and validation are required in the model development. The step toward an accurate model to perform the indented logical design is the model verification. The model operation tracks the chart of the patient/staff flow of the validated conceptual model.

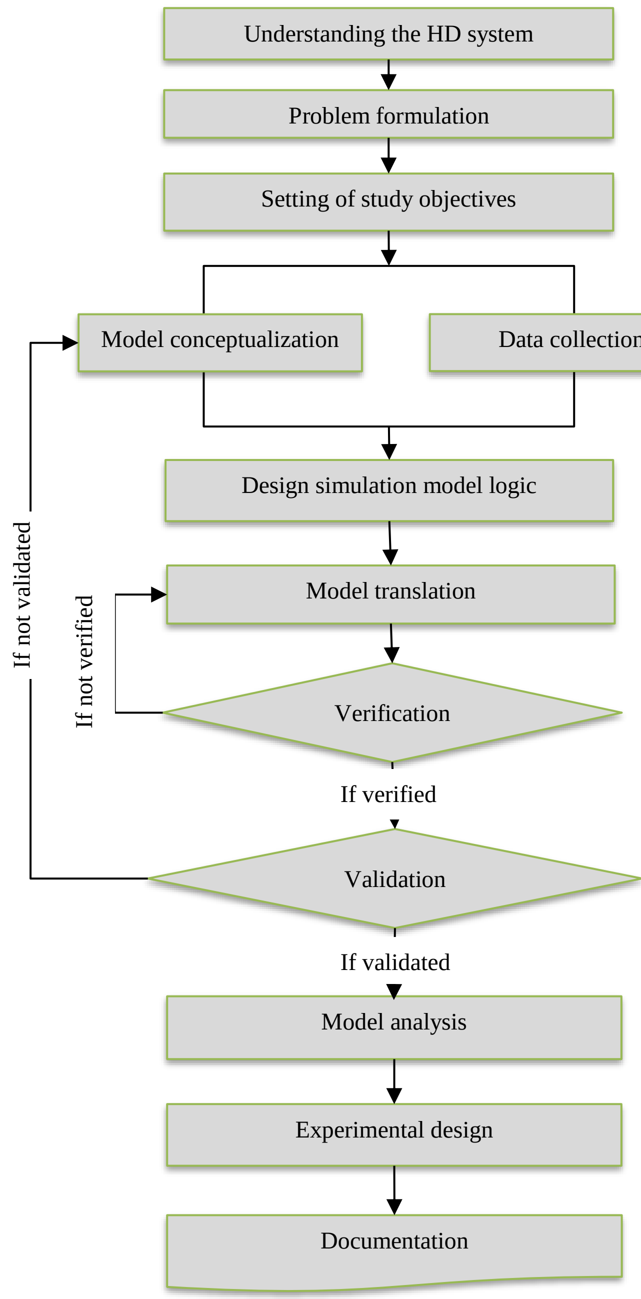

Figure 4-1 General procedure of a discrete-event simulation study [64]

The model validation tests accuracy of the simulation model to represent the real-world system before the model can be used for the system improvement, such as testing a variety of 'what if' scenarios. For solution search of the HD improvement, it is necessary to have a verified and validated model. Once the built model is validated, it is ready to be used as a decision-making tool to analyze effects of different HD operating scenarios on the HD performance.

4.2 Procedures of HD Modeling

Using the DES model, potential solutions can be tested by exploring different scenarios for a consistent and streamlined workflow, efficient process and resource utilization. Impact factors of workflows can also be examined using variations of the system performance identified in the simulation model. A typical patient visit to the HD unit involves different steps as shown previously in Figure 3-2. To understand the HSC HD performance, the entire patient flow is transformed into a simulation model based on the general patient flow description in the flowchart. A variety of HD elements are built in the model. Patients, waiting rooms, dialysis machines and beds, and physicians and nurses are four basic elements in the HD model to represent the dialysis process as shown in Table 4-1.

Table 4-1 Basic elements and their representations in the model

Element Name	Element Description	Element Representation
Patients	Entities flowing through the model	Patients moving through the model
Dialysis machines and beds	Activities that pull entities in, process them, and push them to their next destination	Service stations and treatment processes where patients receive care service
Physicians and nurses	A resource that may be required by other elements for processing, setting up, repair or cleaning	Nurses or Physician working in treatment procedures
Waiting rooms	Queues where entities can be held	Patient waiting in the waiting area

4.3 Simulation Model Logic

A general patient routing logic for the HD model is described in this section. Figures 4-2 and 4-3 present what would happen to a patient from his/her arrival to the process end based on the scheduled time. The dialysis process starts when the patient enters the unit. There are different cycles for patients after being placed on to their beds. In the model, the bed placement decision is dependent on the dialysis machine. As explained before, all machines are setup for beds before patients come to the units. Historical data are analyzed for probability percentages of the HD operation data.

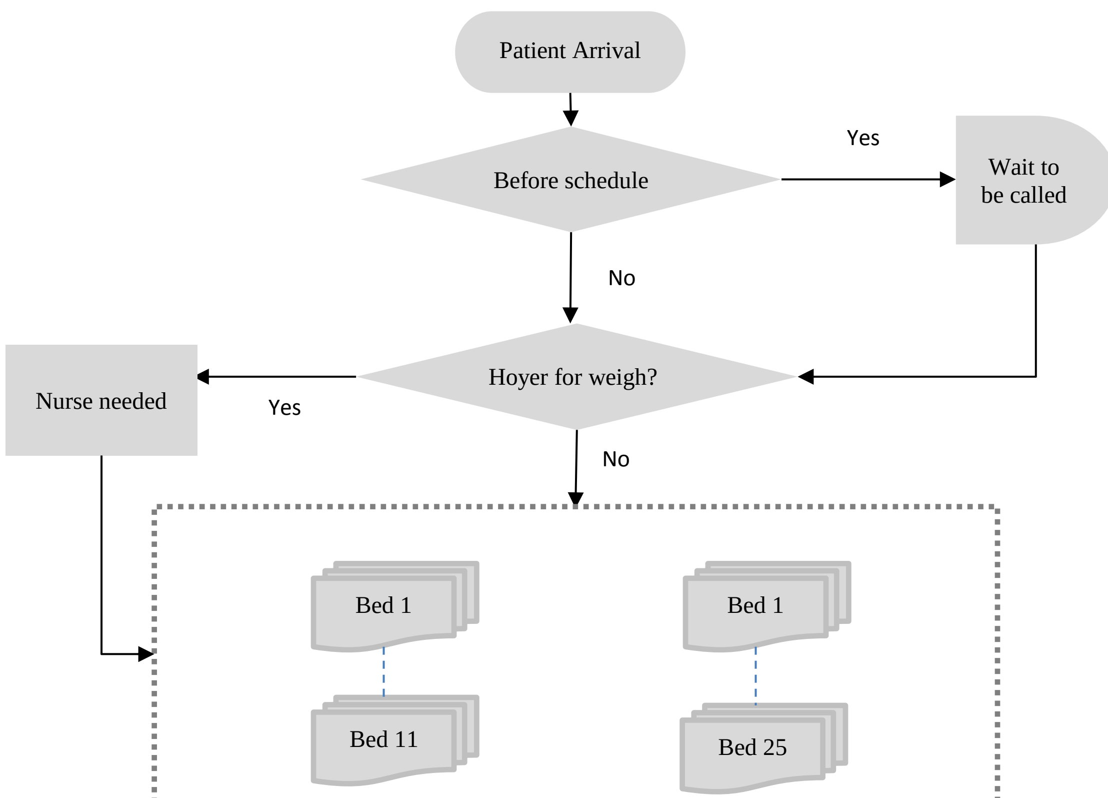

Figure 4-2 Treatment area assignment

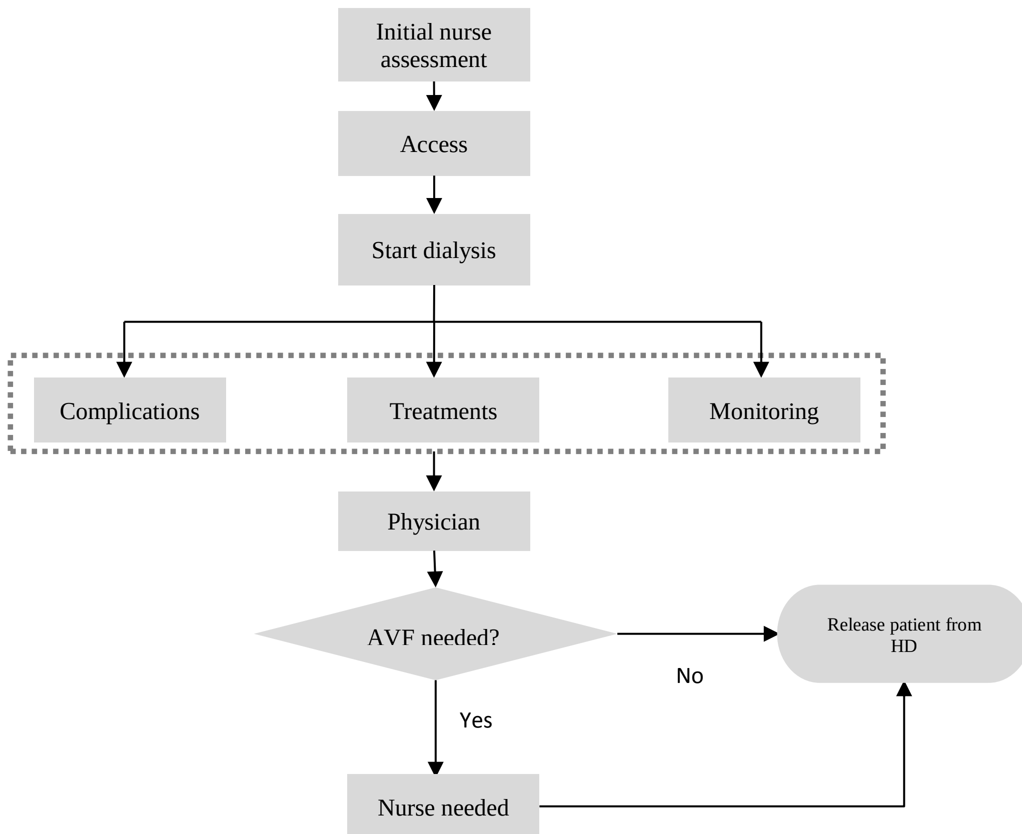

Figure 4-3 Operation procedures for patients after being assigned into a designated treatment area

4.4 Data Collection for the Model Input

Chronic Disease Innovation Centre and Winnipeg Regional Health Authority (WRHA) provided full supports to this research. Information and data were collected for a total of 2122 patients' visits included in historical data of year 2017 gathered from the HD information system, expertise and resources. Paper-based documents used to file data were collected to analyze workflows of HD operations. In addition, a time study was conducted to gather time sensitive data in the patient flow process, from time when patients arrived at HSC HD until the time they left. The survey, given in Appendix A, was designed to follow the patient flow moving through HD units. The model is built using patients' data, treatment procedures of individual patient, and process-time of each treatment procedure.

All records, for each patient, are documented in an excel sheet describing in time, location and status stamps. Model building data are transformed in the format compatible with the Witness software to build the model. Input data for the HSC HD simulation model are discussed as follows.

4.4.1 Patient Arrival Profile

For the arrival pattern in the simulation model, the patient arrival profile is required as one of the most important input data. In the HSC HD units, all the patients are scheduled for one of the three shifts in a day (morning, mid-day or evening) and all the dialysis treatments begin approximately at the same time. As a result, they also end approximately at the same time. According to this, the approach used to schedule the patients results in an acutely heavy workload per nurse at the beginning and ending of each shift. On the other hand, since HD units lack a classification system for patients by needs, or severity of illness, arrival patients are not classified and all of them have the same schedule to start dialysis at 8 am, 1 pm or 6 pm. External transport systems and their availability for HD patients severely impact the patient time on dialysis and their scheduling, which introduces patients into the simulation model with a non-normal pattern in each shift. Therefore, although all patients are scheduled before coming to the units, delays happened for each shift make this irregular pattern. Figure 4-4 shows the average patient visits to the HD per hour of day for two shifts based on three months of collected data.

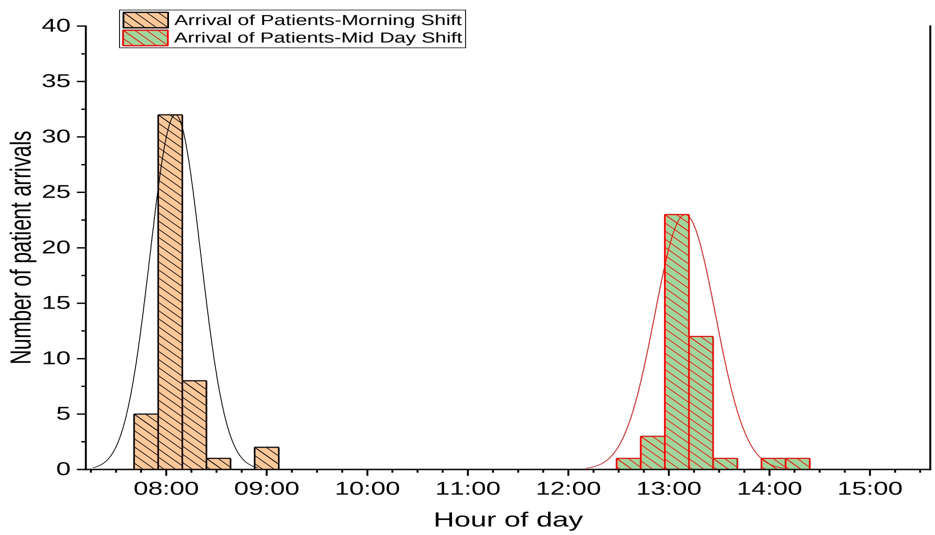

Figure 4-4 Arrival frequency of Patients

The fluctuation of arrival patients reaches its peaks at 8 am and 13 pm (as shifts start). For the simulation model, it can be considered that the patient arrival is stable to be used.

4.4.2 Resource Data

As mentioned in the previous chapter, units A and B consist of several resources including nephrologists, nurses, beds etc. The waiting area capacity and bed resources in these units are shown in Table 4-2.

Table 4-2 Bed resource and waiting area capacity

Waiting area	For units A and B	30 Chairs in hallway
Bed	Unit A	25 Beds
	Unit B	11 Beds

Table 4-3 provides current working schedules and treatment area allocation for nurses in detail. During the dialysis treatment, from patient arrival to leaving time for each shift, each nurse is assigned to take care of patients in a designated treatment area.

Table 4-3 Nurse type, quantity, work shift hours and treatment room allocation

Nurse#	Type	Treatment Area Allocation
Morning Shift: 7:30-12:30 & Afternoon Shift: 12:30-3:45PM (D8)		
1	RN	A 2,3
3	RN	A 6,7
5	RN	A 10,11
7	RN	A 13
8	RN	A 14,25
10	RN	A 17,18
12	RN	A 21,22
14	RN	B 1,2
16	RN	B 5,6
18	RN	B 9,10
Nurse#	**Type**	**Treatment Area Allocation**
Morning Shift: 7:30-12:30 & Afternoon Shift: 12:30-7:45PM (D12)		
2	RN	A 4,5
4	RN	A 8,9
6	RN	A 1,12
9	RN	A 15,16
11	RN	A 19,20
13	RN	A 23,24
15	RN	B 3,4
17	RN	B 7,8
19	RN	B 11
Nurse#	**Type**	**Treatment Area Allocation**
Afternoon Shift: 3:15-5:30 & Evening Shift: 5:30-11:30PM (E8)		
1	RN	A 4,5
3	RN	A 8,9
5	RN	A 1,12
7	RN	A 13
8	RN	A 15,16
10	RN	A 19,20
12	RN	A 23,24

14	RN	B 3,4
16	RN	B 7,8
18	RN	B 11
Nurse#	**Type**	**Treatment Area Allocation**
Afternoon Shift: 11:15-5:30 & Evening Shift: 5:30-11:30PM (E12)		
2	RN	A 2,3
4	RN	A 6,7
6	RN	A 10,11
9	RN	A 14,25
11	RN	A 17,18
13	RN	A 21,22
15	RN	B 1,2
17	RN	B 5,6
19	RN	B 9,10

There is a guide for break times for nurses per shift (Table 4-4). Patient care needs will dictate if break times occur based on the schedule or need to be delayed or staggered. Nurses communicate with CRN's if they have any concerns about taking their breaks and all missed breaks must be preapproved by the director.

Table 4-4 Nurses break schedule guide

SHIFT	**Start time**	**AM Coffee**	**Lunch**	**Afternoon coffee**	**Supper**	**Evening coffee**	**End time**
D8	07:30	09:00-09:20	11:30-12:00	14:30-14:50	---------	-----------	15:45
D12	07:30	09:30-09:50	12:30-13:00	15:00-15:20	16:30-17:00	-----------	19:45
E12	11:15	-----------	13:45-14:15	15:30-15:50	17:30-18:00	20:20-20:50	23:30
E8	15:15	-----------	-----------	16:00-16:20	18:45-19:15	21:00-21:20	23:30
All Coffee Breaks: 20 minutes				All Meal Breaks: 30 minutes			

4.4.3 Service Time

Process time of all treatment procedures is collected from statistical results of historical data. Based on the gathered data, an analysis tool is used to generate appropriate distribution functions for the simulation model. To provide data for the model operation, the discrete data in the data sheet should be converted into distribution functions. For example, Figure 4-5 shows the probability plot of AVF hold for patients in unit A with the distribution function of Log-Logistic (3.15625,0.20672).

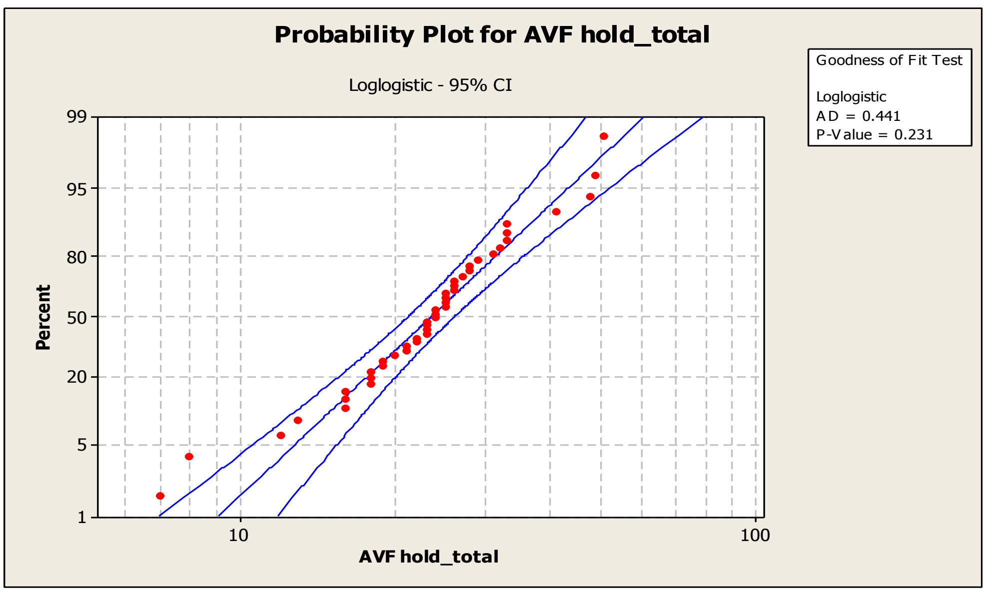

Figure 4-5 AVF hold distribution function

To select the best distribution function, Goodness of fit test is required to compare the gathered data and generated distribution functions. Figure 4-6 presents a sample of the graphic comparison to show the goodness of fit in a distribution to a data set. A software tool is used to generate the green distribution function curve, which fits the blue histogram of the real data. The P-value for this goodness of fit test is 0.231, which implies this distribution function is a good fit to this data set [10].

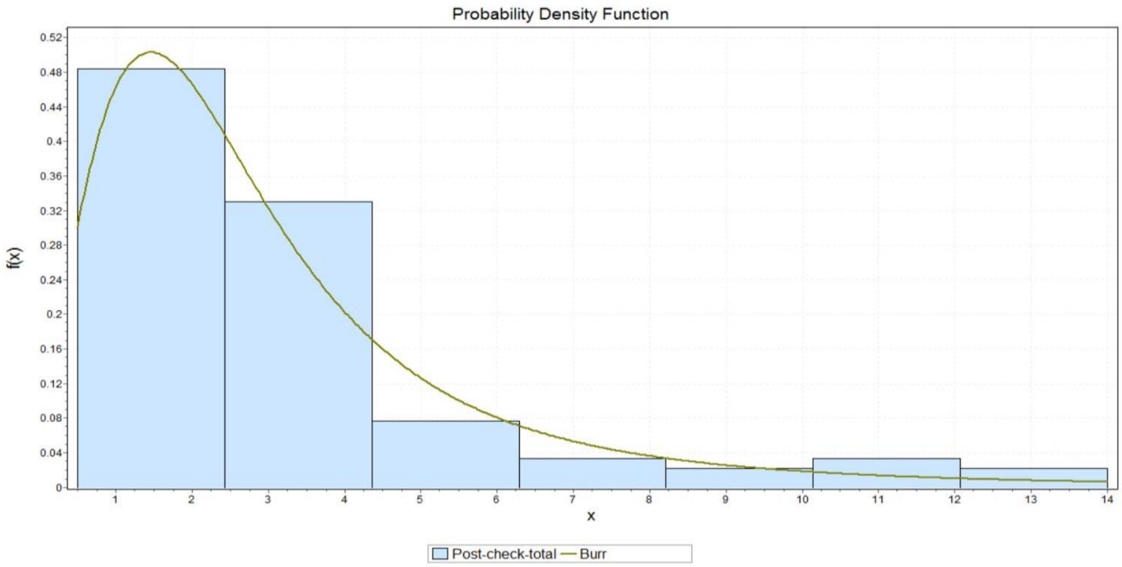

Figure 4-6 Goodness of fit for Distribution Function Generated

Patient Classification Score (PCS) Tool is a standardized tool used in the HD unit to measure patient acuity and nursing care burden during hemodialysis including all levels of care in 7 categories for each patient (Access, Monitoring, Elimination, Isolation precautions, Complication, Treatments, Education/Communication). While patients are dialyzing, they may use a combination of these service stations in the model based on the statistical results of the gathered data. Therefore, all patients are set with a probability to require different levels of care. In other word, for an individual patient, the type of required level of care depends on the pre-determined probabilities. Rather than trying to manually write syntax for all the possibilities in patient treatment procedures, it sounds more reasonable to statistically quantify percentages that patients need. As applying percentages is more representative in DES model building, related probabilities are shown in Table 4-5 (Appendix B shows the full table). In the table, 10.38% of patients require wound care which takes less than 15 minutes.

Table 4-5. Samples of Treatments Distribution

Treatments			Process Time (Minutes)
TRE1	Wound care/dressing change <15 min	10.38%	4
TRE2	Wound care/dressing change 15 - 30 min	2.43%	20
TRE3	Wound care/dressing change >30 min	0.71%	35
TRE4	Foot assessment	11.95%	3
TRE5	Dialyzer clotted/new set up	1.29%	6
TRE6	Recirculation bloodwork	3.52%	2
TRE7	IV antibiotic	9.95%	2
TRE8	IV iron loading dose	3.95%	2
TRE9	Continuous infusion from ward	1.00%	2
TRE10	Bloodwork other than routine monthly	18.19%	1
TRE11	Blood product administration	0.00%	-
TRE12	Medications po/routine iv	36.63%	0.5

Moreover, as mentioned before, the service stations' process time for each cycle of care in the model is generated by the corresponding distribution function. The amount of time required by a nurse to spend with patients in each service station is identified in the time study and recorded in the historical data. Table 4-5 presents the processing time input for the model in each level of care based on collected data. The median time is considered for each item of 7 categories and for other service stations, the distribution functions are provided in Table 4-6. As it shows, the distribution function of initial nurse assessment is Log-Logistic (3.5119, 4.3835).

Table 4-6 Distribution Function of service stations

Service Station	Process time
Using Hoyer	Johnson SB (0.65008, 0.52906, 5.6086, 0.81572)
Initial Nurse Assessment	Log-Logistic (3.5119, 4.3835)
Access	Burr (0.51464,3.4058, 2.9083)
AVF Hold	Cauchy (3.9872, 23.584)

Post Check	Burr (1.3382, 1.9003, 3.0009)

4.5 Model Verification and Validation

During the simulation model development, the model must be evaluated through the verification and validation to investigate the accuracy and credibility of the built model. The model should be checked to meet specifications and represent the real-world system for the ultimate goals [65]. The model design, problem solving, and continuous improvement are some aspects for a credible model used to support the decision making [54].

With this intention, after documenting functional specification and completing the initial model, the model verification and validation are required to achieve a credible model. A verification procedure is conducted to confirm the model to the conceptual model. It is to check whether the model is correctly implemented and working as intended. On the other hand, in the model validation, comparing the model output with the real data is needed for checking the model to represent the real system [66].

4.5.1 Model Verification

The process of verifying the code and logic of a model is called verification [67]. In fact, for model building, every iteration requires to be verified. Since several smaller codes are required for building the model in each iteration, each of these codes can be built into a dummy model to be verified separately. There are two types of errors in a code identified by conducting verification: syntax and logic. A simple spelling mistake is syntax that the software captures it very easily. Witness is able to detect certain errors and reports them in the system. When the code is called for something that does not exist, errors are reported. Witness provides users with detailed information about errors such as source and the exact time of errors. Identifying the cause of an error and then solving it results in fixing the code. Although verification of syntax errors is simple, and the model automatically detects and catches them very easily, the model logic is still required to be verified. Since some codes only work for a range of values and fail beyond that range, it is important to verify a code for a range of situations. Verification of model logic would be tricky since detecting logic errors are harder than syntax errors. Witness has several inbuilt tools to help users such as a tool called step debugging to verify the written codes and behaviour of the model. In this regard, instead of identifying sources of errors in a running model, the user can start and stop the model in specific points.

In addition, different ways can be used to verify a simulation model including incremental model building, consistency test, expert evaluation and internal evaluation [67]. Another approach applied to verify the HSC HD simulation model is incremental model building. Using this method, to ensure that the model is rightly and logically coded, the model is built in small sizes and then is expanded to the completed model. There are three steps used to represent the verification process applying incremental model building method. First, the model is built from arrival of patients to the time of dialysis machines start working. After the first step's verification, the model is simulated from arrival of patients up to the stage of dialysis machines stop working. Finally, in the last step after verification of step two, the completed model from patients' arrival to leaving the units is built.

Another technique, commonly used to verify a simulation model, is by generating a variable/attribute output file in which data (wait-times, process times attributes etc.) for each patient are recorded [10]. All the output files were scanned for any anomalies in the simulation model of HD. Other than this, another approach to conduct the model verification is to trace the model animation to detect conceptual errors by studying animated entities to remove mistakes in the model [65].

4.5.2 Model Validation

For the model validation, 1061 patients' historical data of the second two weeks were used to compare data that the model results in 2 weeks running (the first two weeks were used for verification). There are 3 performance measures used in the model validation: the average length of stay of patients per shift in the unit, daily throughput of patients, and average waiting time of patients to start dialysis. Table 4-7 shows the comparison of the real HD data and simulated data.

Table 4-7 Comparison of HD performance measures for model validation

Performance measures	**Real HD data (mean)**	**Simulated data (mean)**	**Discrepancy (%)**
Length of stay (LOS)	278.93	265.71	-4.74
Wait Time to Start Dialysis	18.10	17.45	-3.59
Patient Daily Throughput	108	107	-0.93

As shown in Figure 4-7, the accuracy of the model output for these performance measures is very high; the discrepancy is very low. Therefore, it proves that the right model is built, and data and process used were correct.

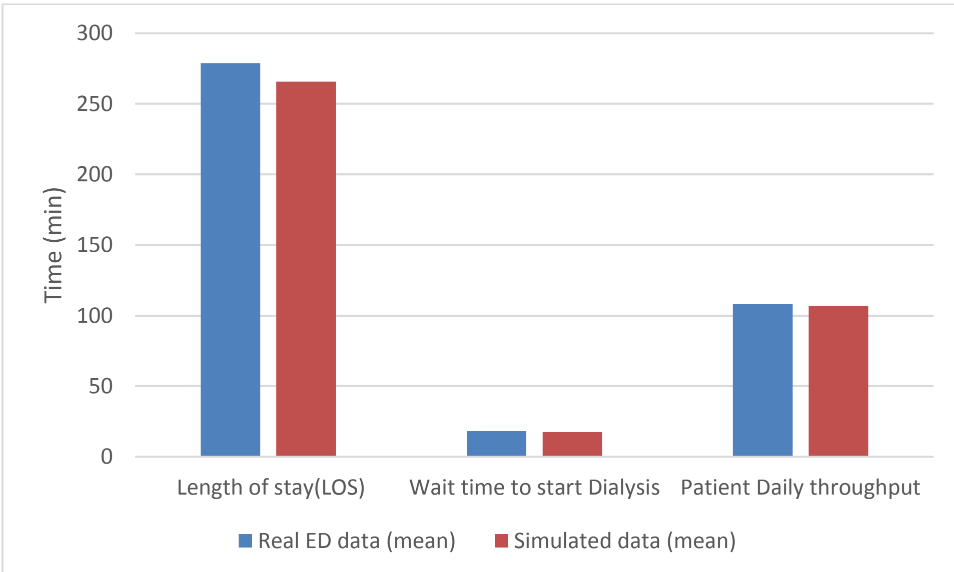

Figure 4-7 Comparison based on the discrepancy

As shown in Table 4-7, the model is reasonably close to real HD, which shows that the model is qualitatively validated. However, it is required to conduct a robust quantitative analysis to ensure that the simulation model is validated. For validation, the proper statistical test should be determined. In this regard, data sets should be analyzed for normality since different tests are used to analyze normal and non-normal data. Conducting normality test using Minitab, distributions resemble nonparametric data i.e. data sets are not normal. As a result, Mann-Whitney U test, a non-parametric test, is used for comparing data sets. Significant value, Z-value, or critical value are referring to the same concept which can be calculated as a function of means of both data sets and variance. The Mann-Whitney U test is conducted in Minitab and the test results are shown in Table 4-8.

Table 4-8 Mann-Whitney U Test Results for HSC HD model

Variable: LOS	Mean	Median	Man-Whitney Test	
			Z	P-Value
Data	278.93	275.30	-0.80	0.026
Model	265.71	261.90	-0.65	0.052

After conducting a test of validation, hypothesis testing is applied to see whether there are statistically significant differences in LOS and WTSD for model output data and system validation data. Following tests are conducted:

1. Hypothesis test for WTSD

Null hypothesis (H0): There is no statistically significant difference in the mean of the model output data and the mean of the model validation data for WTSD; i.e., the model is validated.

Alternative hypothesis (H1): There is statistically significant difference in the mean of the model output data and the mean of the model validation data for WTSD; i.e., the model is not validated.

2. Hypothesis test for LOS

Null hypothesis (H0): There is no statistically significant difference in the mean of the model output data and the mean of the model validation data for LOS; i.e., the model is validated.

Alternative hypothesis (H1): There is statistically significant difference in the mean of the model output data and the mean of the model validation data for LOS; i.e., the model is not validated.

Based on hypothesis testing results, the p-value of 0.052 and 0.180 is observed for LOS and WTSD respectively. The null hypothesis is failed to reject since both p-values are greater than the significant level of 0.05. Therefore, the model is now validated and available for further analysis.

Chapter 5

Model Analysis and Scenario Design

This chapter describes results of scenario testing at HSC HD units. In the following sections, bottlenecks in the existing system are identified and process change solutions to alleviate them are proposed. In this chapter, three proposed improvement strategies and scenarios are developed in collaboration with the MRP team. The built simulation model is used to estimate strategies and simulation outputs for performances of proposed scenarios. To maximize the positive impact of improvement strategies, the combination of specific scenarios is also identified.

5.1 Problems of Variable Workloads

Complications during dialysis can create delays in the patient flow. Such issues may include the bathroom requirement, high blood pressure, low blood sugar, passing out, cramping, Rigor’s chills, and Septic shower or problems with the dialysis machine. Another main problem in the dialysis unit is variability exemplified in dialysis scheduling. As a matter of fact, fluctuating patients’ demands during dialysis treatments, altering the numbers of patients on dialysis machines in the unit in a shift due to different durations of treatment times, and changing staff availability could be considered as variability in the unit. In order to improve efficiency and capacity, enhancing flexibility is necessary in the system. For example, adding a float nurse in some dialysis units or using available staff as backup are addressed to create flexibility [68-70]. As actual time on dialysis is the rate-limiting step through the whole process in the unit, initiation and termination of sessions must be efficient using the maximal resources. With this intention, to improve the efficiency of the patient flow, some units use trained resource nurses to enhance patients' experience by supervising and troubleshooting the initiation and termination of their dialysis.

According to patient's perspective, if any part of the dialysis process takes longer than planed time, it is called a defect that creates a bottleneck in the patient flow and results in failure to meet patient needs. As a result, the patient must wait for expected services, which would worsen the patient experience. In addition, there are other factors contributing to delays including patient arrivals or availability of the dialysis station. All these issues could cause bottlenecks that result in patient wait time increment. In fact, forcing patients to wait for the dialysis station to be ready has different consequences. Reduction of the dialysis time to meet precise transportation time or causing delays on later shifts due to passing the scheduled times are some of these effects. To minimize such drawbacks, detecting the patient flow bottlenecks should be considered as the first step.

5.1.1 Bottleneck Detection

As previously stated, bottlenecks are factors preventing an efficient HD unit. Therefore, it is a necessity to first identify bottlenecks in the dialysis unit. For this purpose, specific components resulting in blockage of the patient flow must be revealed.

To detect bottlenecks within the existing patient flow, a method of evaluating “criticality indicator” for each service station is applied and critical stations would be found by comparing results [71]. To calculate the criticality indicator for the ith service station, simulation statistics are investigated. For this purpose, the difference between individual rates for each service station (i.e. the average rates of utilization, waiting for labor, starvation, blocking) and the whole system average for that rate is calculated by applying Equation 5-1.

$$KR_i = \left(\frac{\sum_{i=1}^{n} B_i}{n} - B_i\right) + \left(I_i - \frac{\sum_{i=1}^{n} I_i}{n}\right) + \left(BL_i - \frac{\sum_{i=1}^{n} BL_i}{n}\right) + \left(L_i - \frac{\sum_{i=1}^{n} L_i}{n}\right) \qquad (5\text{-}1)$$

Where KR_i is the criticality indicator for the ith service station (%), B_i is the average utilization rate of the ith station (% Busy), I_i is the average starvation rate for the ith station (% Idle), BL_i is the average blocking rate of the ith station (% Blocked), L_i is the average waiting rate of labor for the ith machine (% Wait for labor).

To identify the severity of each station, the indicator evaluation is applied to allow detecting the critical stations [71]. The service station with the minimal value of KR_i is indicated as a bottleneck which may need capacity building, while the station with the maximal value of KR_i is regarded as a station allowing a better utilization.

For all different service stations within the HD model, criticality indicators are investigated by applying the aforementioned approach. Since the dialysis machine and bed for each patient are modeled separately, two groups of KR_i values are reported as in Figures 5-1 and 5-2. Figures 5-1 and 5-2 show graphical results of the bottleneck analysis for beds and dialysis machines respectively. As shown below, criticality values for some beds and dialysis machines in the hemodialysis unit are extremely low. Therefore, to have a smoother patient flow, the top priority should be given to these stations that cause blockage in the flow.

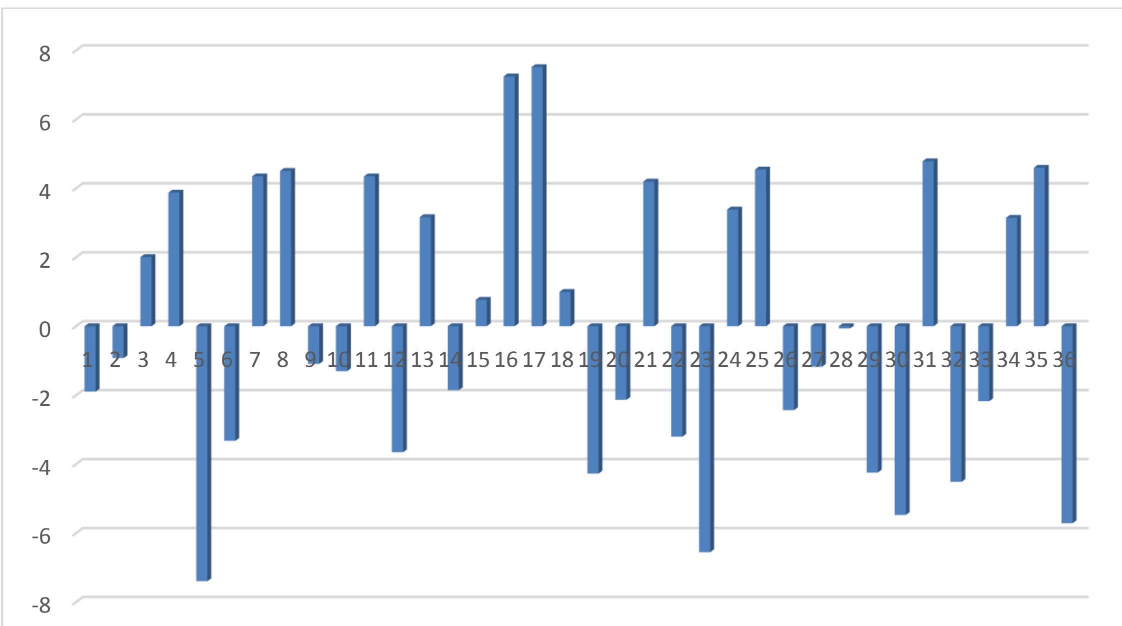

Figure 5-1: Results of the bottleneck analysis on HD beds using the criticality indicator-based method

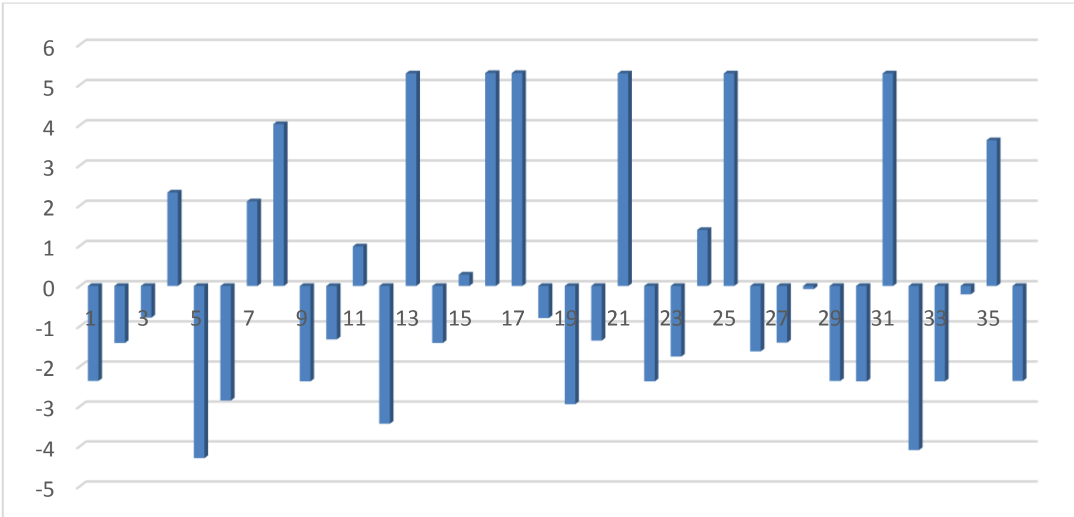

Figure 5-2: Results of the bottleneck analysis on dialysis machines using the criticality indicator-based method

Moreover, analyzing the criticality values for all HD nurses in their assigned shifts during a day is conducted by implementing the same method to indicate possible resources that result in having a blockage in the flow. Nurses work in four different shifts and results must be conducted for each of them. On day and evening shifts, nurses are assigned to the beds differently. Schedule details on nurse allocations are introduced in Section 4.4.2. Figures 5-3 to 5-6 demonstrate results of the bottleneck analysis for nurses in each shift. Nurses working based on schedule E8 with maximal KRi provides the possibility of a better utilization. However, hardly low values are observed for almost all the nurses scheduled as D8 and D12 in Figures 5-3 and 5-5, respectively. Therefore, the focus for improvement is given to these resources as potential limiting factors making delays in the work flow.

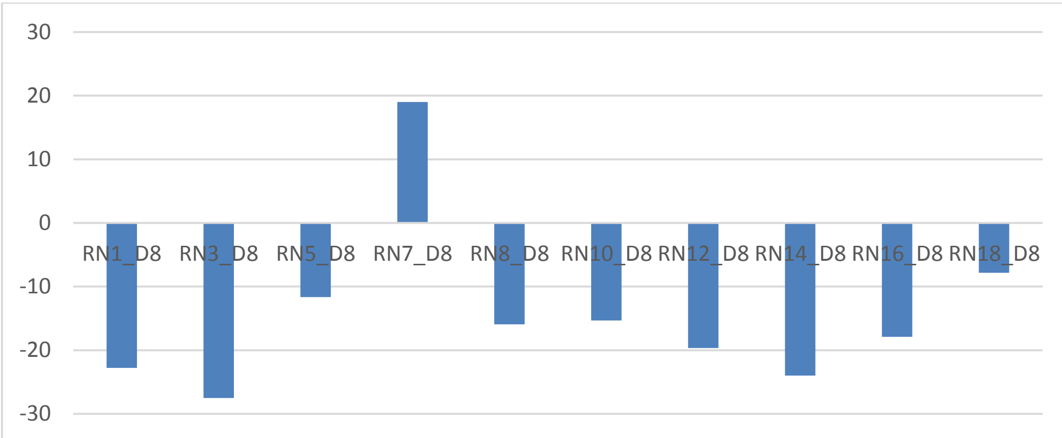

Figure 5-3 Results of the bottleneck analysis on D8 nurses using criticality indicator-based method

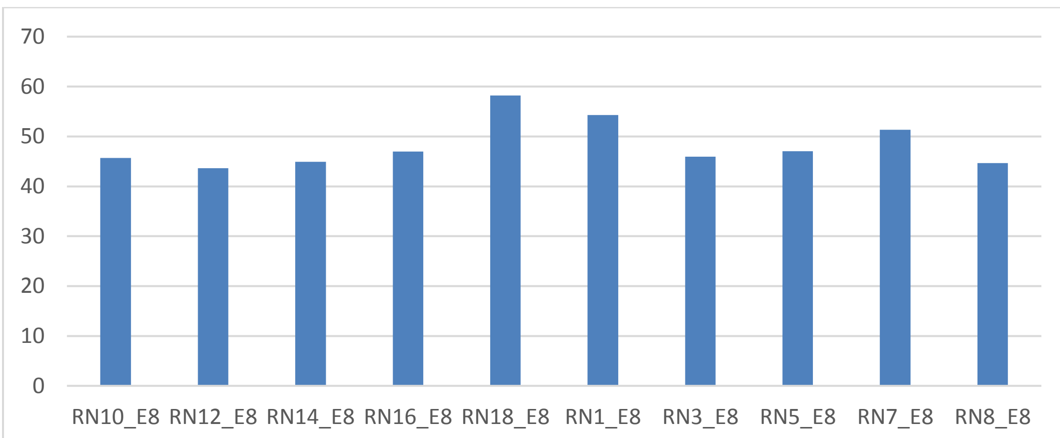

Figure 5-4 Results of the bottleneck analysis on E8 nurses using criticality indicator-based method

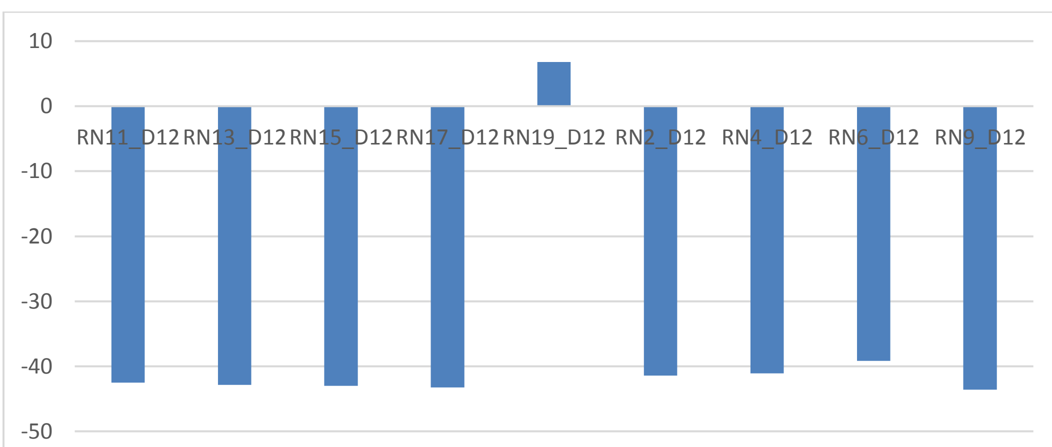

Figure 5-5 Results of the bottleneck analysis on D12 nurses using criticality indicator-based method

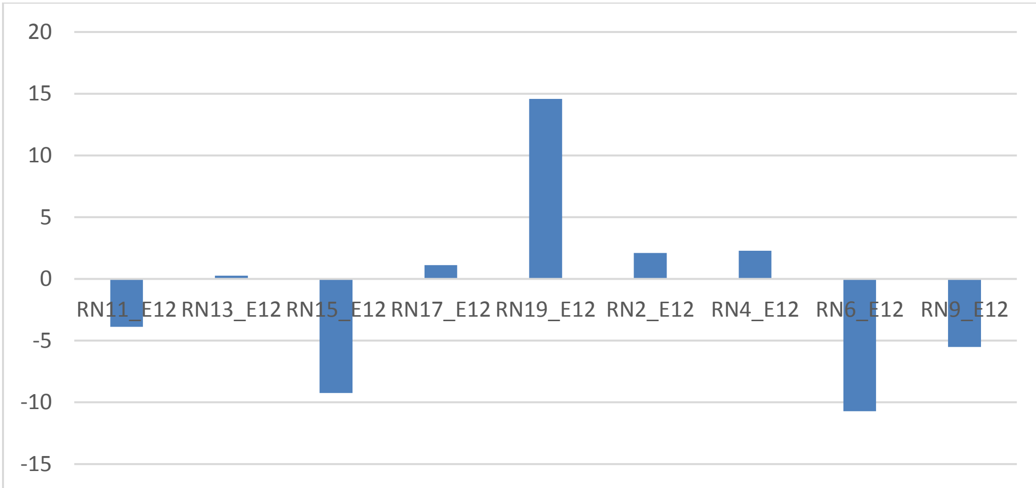

Figure 5-6 Results of the bottleneck analysis on E12 nurses using criticality indicator-based method

Alternative strategies are proposed for the HD unit performance improvement by addressing the system bottlenecks in the following section.

5.2 HD Improvement Strategies

HD unit improvement is required for the patient flow, scheduling and waiting time. To determine factors that account for these issues, the investigation indicates that HD patients spend most of their time waiting for put-ons and takeoffs caused by limitations of resources including Hoyers and nurses, and conflicts of shifts due to inefficient scheduling [3]. As previously described, put-on is to connect to the vascular access in the session initiation, and takeoff is to disconnect it at the session termination. As a matter of fact, the duration that a dialysis machine works cannot be altered, which is fixed, therefore, there will be no reduction in dialysis machines' working time. In this regard, minimizing the effect of existing deficiencies is the basis of HD improvement.

Key performance indicators (KPIs) need to be defined to measure the HD unit performance quantitatively [72]. In this study four KPIs are defined as follows.

1. Percentage of times that dialysis machines start within 15 minutes (from patient arrival until the dialysis machine starts)
2. Percentage of times that dialysis machines start within 20 minutes
3. Wait-Time to Start Dialysis Machine (WTSD) (time duration for patient arrival, weight measurement, initial assessment by a nurse and put-on)
4. Length of stay (LOS) (time interval between patient arrival and departure from the unit)

The main reason for defining five minutes difference between two of the key indicators is to achieve a better understanding and analysis from the system. This will be further clarified when results are presented.

To achieve reduction in the pre-defined four KPIs, the focus is given to input and output phases of patient's journey in the HD. For this purpose, KPIs must be measured and monitored in current state of the system as well as after improving it. Comparing KPIs' results for these two stages, HD unit's performance can be investigated quantitively.

Strategies used in solution searching to help alleviate all the four KPIs generally fall into following three groups in this study:

1. Float Nurse Strategy
2. Changing break times for nurses
3. Staggered Start Time Strategy

For the proposed strategies, several alternatives are tested. Since staggered start time has a significant effect on system scheduling, it is considered as the main improvement strategy in this work. Moreover, results of the combination of scenarios testing are presented, detail for these solutions are discussed in following sections.

5.2.1 Float Nurse Strategy

To cover the shortage of staffing in different stations of a unit, floating is a form of resources that some healthcare services use. Adding such a floating resource, the system can benefit from modified need of nursing care services, covering absent staff, and satisfying special needs of different service stations [73]. In some cases, a more experienced nurse must float out of turn to cover duties of an assigned nurse to a service station who is busy with other tasks. In fact, to have a smoother patient flow, dialysis units with a higher level of nursing experience show better performances compared to dialysis units with less experienced nurses [69]. Occasionally, delays in stations are expected with the shortage of nursing experts. Compared to unit staff nurses, a float nurse has a tendency toward receiving more difficult patient assignments. While the assigned nurse to a bed is busy, the expert nurse is going to float to lower the waiting time for the patient [70].

The purpose of this section is to examine the problem regarding the shortage of nurses and evaluate KPIs regarding the use of float nurses to provide patient care in the HD. In other words, this section specifically presents the solution of adding float nurses at time of high workloads for nurses.

Traditionally in dialysis settings, nurses take the responsibility to conduct and handle all the steps in getting a patient started on dialysis. Since all patients are scheduled to start at the same time and consequently end at the same time, nurses' stress level is high in the procedure of put-ons and takeoffs. In fact, they must prioritize and finish multiple tasks leading to errors and time delays. Such delays happen due to fact that the allocated time is not enough for finishing all the steps. Delays would be one of the factors that prolong the entire treatment cycle and result in the longer length of stay for the patient, conflicting shifts, and lack of nurses during put-ons and takeoffs. Since the most time-consuming parts are getting patients started and then off the dialysis machines, adding a float nurse can reduce put-on and takeoff times in the patient treatment process. Furthermore, using float nurses, patients will benefit from the immediate getting on/off dialysis machines without waiting for a long time.

Instead of the current nurse model, a float nurse-based model is proposed as an enhancement alternative. This improvement scenario simulates how KPIs are affected if float nurses are hired. Different scenarios are defined and simulated for adding 1 float nurse and 2 float nurses for doing put-ons and takeoffs.

5.2.1.1. Experiments Design for Float Nurse Strategy

To evaluate effects of adding the float nurse strategy on KPIs, scenarios for experiments are designed in two aspects: 1) location of assignments 2) number of float nurses. As previously stated, in the HD unit, patients are not identified by the type of access, (i.e. AV-F or Central line) and the difference can create different set-up times, delays and issues during dialysis. Problems with connecting and disconnecting to vascular access can create delays that extend patient's dialysis process. Such problems would arise if a nurse needs to focus on a single patient's issue and other resources are not available to cover the other patients in the unit. For example, if a back-up resource is away on break, or if a nurse needs to take a patient to ER and leave the other patients in the unit with only one nurse. Moreover, nurse assessments are not standardized and the time they spend with patients is different. Therefore, the assignment of float nurses occurs at the start and end of each shift in potential bottleneck stations when connecting and disconnecting to the vascular access is happening. In fact, to address such issues, float nurses are first added for both put-ons and takeoffs. Table 5-1 shows how the four pre-defined KPIs are affected.

Table 5-1: Results of KPIs by adding float nurses for put-ons and takeoffs

Index	Alternatives	within 15min			within 20min			LOS (Min)			WTSD (Min)		
		Base	New	Effect	Base	New	Effect	Base	Mean	Effect	Base	Mean	Effect
1	Add 1FN for put-on and takeoff	50%	52.44%	2.44%	69.44%	79.25%	9.81%	265.71	266.4	0.69%	17.45	14.56	-2.89%
2	Add 2 FNs for put-on and takeoff		71.32%	21.32%		91.10%	21.66%		264.85	-0.86%		13.27	-4.18%

Five Minutes difference is added to the first KPI to define another key indicator (within 20 min), which further highlights the effect of adding float nurse in the unit. For example, adding 1 float nurse and considering within 15 min indicator, results show less than 3% improvement. It is while within 20 min indicator shows about 10% improvement with respect to the base system without adding any float nurses. In particular, by adding 2 float nurses during put-ons and takeoffs, in 91.10% of the time, it would take less than 20 minutes to start the dialysis machine, which is a great level of improvement in the system.

It is worth to mention that a high portion of LOS is contributed to the dialysis machines working time which is fixed and equal to 210 minutes (3 hours and 30 minutes) in this study. Therefore, the effect of any improvement must be considered only on initiation and termination processing time.

In order to differentiate the effect of adding float nurses on put-ons and takeoffs, Table 5-2 shows results of adding the float nurse only during put-ons.

Table 5-2: Results of KPIs by adding float nurses for put-ons

Index	Alternatives	within 15min			within 20min			LOS (Min)			WTSD (Min)		
		Base	New	Effect	Base	New	Effect	Base	Mean	Effect	Base	Mean	Effect
1	Add one float nurse for put-on	50%	55.56%	5.56%	69.44%	83.33%	13.89%	265.71	263.65	-2.06%	17.45	13.97	-3.48%
2	Add two float nurses for put-on		75%	25%		97.22%	27.78		262.77	-2.94%		12.27	-5.18%

KPIs of the current situation are compared with new results. Better results are achieved for KPIs after improvement in this scenario. It shows a general great increase in percentage of times that dialysis machines start within 20 minutes by adding float nurses for connecting to the vascular access. Moreover, compared to the reduction in LOS with WTSD, the reduction in LOS fluctuates less strongly than the reduction in WTSD.

As a result, adding float nurses only during put-ons is a better option and shows more effect on the system performance. Notably, adding float nurses more than two shows saturation in system improvement and results are excluded accordingly.

Although adding 2 float nurses shows a higher level of improvements in KPIs, only 1 float nurse might be used in the real system. Having access to other economical improvement strategies and limitations in budget are among reasons for hiring only 1 float nurse.

5.2.2 Changing Break Time for Nurses

This improvement scenario simulates how KPIs would be affected if current nurses' break time was shifted to better meet demand. Since in some cases delays are due to absenteeism of nurses in high demand time during the dialysis treatment, current schedules of break time for nurses are altered. Changes resulting from analysis of nurses scheduled in E8 and E12 can be seen in Tables 5-3.

Table 5-3: Changing break time for E8 and E12 nurses

SHIFT	Shift Time	Old Break time	New Break time
E12	11:15-23:30	13:45-14:15	14:15-14:45
E8	15:15-23:30	18:45-19:15	19:15-19:45

Each KPIs is determined after applying this scenario in the model. Results are shown in Table 5-4.

Table 5-4: Results of KPIs by changing break time for nurses

	Baseline	New Results	Effect
Within 15 min	50%	53%	3%
Within 20 min	69.44%	70.60%	1.16%
WTSD (Min)	17.45	16.50	-0.95%
LOS (Min)	265.71	264.70	-1.01%

In Table 5-4, a slight decrease in WTSD and LOS may be observed as well as very low increase in two other KPIs. Changing break time for nurses scheduled in E8 and E12 causes an improvement on KPIs however it might be considered as unacceptable level of improvement. This scenario is not improving the system performance as expected since the suggested changes are not in the initiation and termination of sessions.

5.2.3 Staggered Start Time Strategy

Hectic scheduling in HD units can result in patients and staff dissatisfaction and increasing waiting time. Staggered start time is one of the improvement methods that can result in a dependable start and end dialysis time with more control on overall system performance accordingly. Such dependability can also help with a better interaction and balanced demand between staff and patients (especially during put-ons and takeoffs), providing predictable shift times, and a cost-effective and productive unit in overall [3].

Before applying any changes in the HD unit scheduling, the current patient flow is carefully investigated. A detailed view of the patient flow is defined as the number of patients per hour who are being put on or taken off the dialysis treatment in accordance with staff availability during the same time. It has been revealed that starting patients' dialysis treatment at similar time results in more overlaps between put-ons and takeoffs, and busier and more stressful time intervals for patients and staff (specially at the beginning and end of the shifts). It also becomes clear where delays and waiting occurred for the next shift of the same station in the unit. Furthermore, staff underutilization occurs during patients' low demand periods while the busy ones cause staff capacity overwhelming.

First, the HD unit scheduling is presented in detail. Patients are scheduled in three shifts starting at 8:00 AM, 1:00 PM, and 6:00 PM in the current system. Thirty-six patients are assigned to each shift without considering the type of their access, duration of dialysis treatment, delays in previous shifts, and staff availability. This can result in simultaneous patient turnovers and off-schedule beginning and conflict of the following shifts. Such delay can get even worse when patients arrive simultaneously at the unit in the next shift. As patients' arrival initiates a chain of steps to be done before starting the dialysis machines (including weight measurement, initial nurse assessment, setting vascular access), their simultaneous presence at the unit forces a high workload on the nurses. Considering the fact that each nurse covers at least two beds, this will cause even more delay in patients' treatment.

To overcome the aforementioned problems, staggered start time can be applied on the simulation model of the HD unit. In this method, patients' arrival is rescheduled to ensure different start time of dialysis treatment and helping the overall performance of the system by reducing time delays. Improving KPIs of the system during the first shift, staggered start time can affect second and third shifts as well. Different scenarios are defined for applying staggered start time on the HD unit to improve the system performance.

5.2.3.1. Experiments Design for Staggered Start time Strategy

Initially staggered start time strategy is applied in the model for 15 minutes time intervals which is developed in collaboration with the MRP team. Starting at 8:00 AM, 9 patients are scheduled for each 15-minute time interval. Therefore, patients' entrance to the model happens between 8:00 AM and 8:45 AM for 36 patients of the first shift as shown in Table 5-5.

Table 5-5: Staggered start time application (op2)

OP2	Start Time	8:00am	8:15am	8:30am	8:45am
	# Patients	9	9	9	9

Applying the time schedule of Table 5-5, each KPIs is determined from the model and following results are achieved.

Table 5-6: Results of KPIs by applying staggered start time (op2)

	Baseline	**New Results**
Within 15 min	50%	44.45%
Within 20 min	69.44%	63.12%
WTSD (Min)	17.45	20.63
LOS (Min)	265.71	273.38

In Table 5-6, baseline and new results information refer to the system performance before and after applying staggered start time, respectively. Percentage of times where patients' dialysis starts within 15 or 20 minutes is now reduced by around 5% and 7% respectively. Average waiting time of patients for commencement of dialysis machine is now increased by 4 minutes and the overall length of stay is augmented by 8 minutes.

Therefore, the suggested scenario for applying staggered start time is not improving the system performance as expected and it must be modified.

For such modification, the whole scenario was reanalysed. It was revealed that in the first proposed scenario patients' input in the simulation model was not acceptable. At some time-intervals, some nurses had to cover their two assigned patients (ratio of nurses to patients is 1:2) while others were left without any patients. For example, in the first 15 minutes, 9 patients enter the unit and 9 nurses are expected to start working on them. However, since each of those 9 nurses is assigned to two beds, some of them will receive two patients leaving other nurses without any patients. Such working schedule introduces more delay in patients' treatment since one nurse must cover two beds simultaneously. To guarantee that nurses cover at least one patient in each time-interval, two beds for each nurse are separated into two different groups as in Table 5-7. By assigning patients separately to each group, it is now possible to ensure that each nurse will not receive more than one patient in each time-interval.

Table 5-7: Groups of beds for nurses

Groups	**1**	A2	A6	A10	A14	A17	A21	A4	A8	A1	A15	A19	A23	A13	B2	B6	B10	B4	B8
	2	A3	A7	A11	A25	A18	A22	A5	A9	A12	A16	A20	A24	B1	B5	B9	B3	B7	B11

To further investigate the performance of the modified strategy for assigning patients to beds, more scenarios are defined based on investigations under supervision of managing board of WRHA and HSC HD units. Tables 5-8 to 5-13 are achieved for applying staggered start time strategy.

Table 5-8: Staggered start time application (op1)

OP1	Start Time	8:00am	8:15am	8:30am	8:45am	9:00am
	# Patients	6	6	6	9	9
	Group #	G1			G2	

Table 5-9: Staggered start time application (op2)

OP2	Start Time	8:00am	8:15am	8:30am	8:45am
	# Patients	9	9	9	9
	Group #	G1		G2	

Table 5-10: Staggered start time application (op3)

OP3	Start Time	8:00am	8:30am
	# Patients	18	18
	Group #	G1	G2

Table 5-11: Staggered start time application (op4)

OP4	Start Time	8:00am	8:15am
	# Patients	18	18
	Group #	G1	G2

Table 5-12: Staggered start time application (op5)

OP5	Start Time	8:00am	8:15am	8:30am	8:45am	9:00am	9:15am
	# Patients	6	6	6	6	6	6
	Group #	G1			G2		

Table 5-13: Staggered start time application (op6)

OP6	Start Time	8:00am	8:30am	8:15am	8:45am
	# Patients	9	9	9	9
	Group #	G1		G2	

Applying staggered start time based on six different operations shows following results for four KPIs (Table 5-14).

Table 5-14: Results of different staggered start time applications on KPIs

	Baseline	**OP1**	**OP2**	**OP3**	**OP4**	**OP5**	**OP6**
Within 15 min	50%	52.78%	63.89%	69.44%	58.33%	52.78%	55.56%
Within 20 min	69.44%	58.33%	75%	83.33%	70%	61.11%	66.67%
WTSD (Minutes)	17.45	18.53	16.74	15.11	15.63	20.29	18.1
LOS (Minutes)	265.71	259.95	258.16	258.10	263.46	261.83	264.53

Analyzing results reveals that operations 2 and 3 suggest the better improvement in the system performance. Between these two operations, OP3 is selected due to a higher enhancement in KPIs. For example, 83% of time the dialysis machines start within 20 minutes. To visually observe effects of applying different operations, Figures 5-7 and 5-8 are plotted to compare measures of KPIs with the baseline model performance.

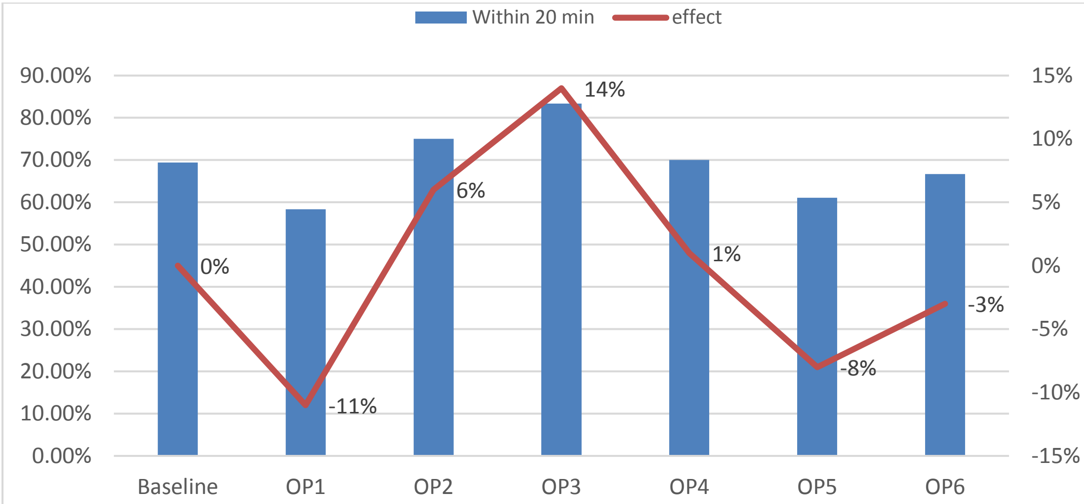

Figure 5-7: Percentage of times dialysis machines start within 20 min: Evaluating improvement scenarios

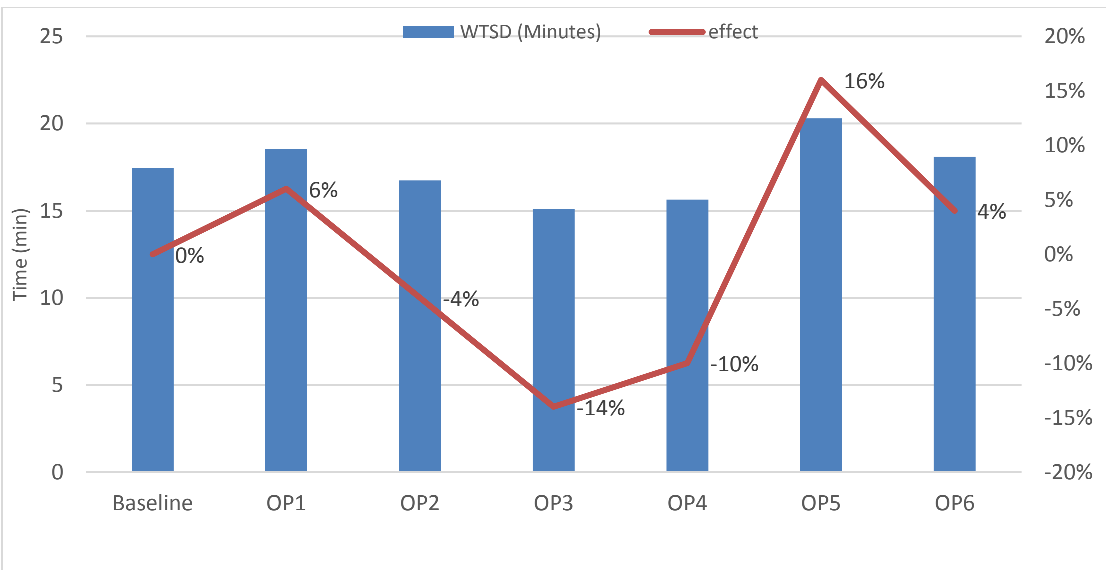

Figure 5-8: Waiting time to start dialysis: Evaluating improvement scenarios

As previously discussed, for example, since 210 minutes of LOS time are always considered as dialysis machine's fixed working time, 7.55 minutes reduction in the indicator for OP2 is achieved out of 55.71 minutes (not the whole 265.71 minutes). The 55.71 minutes is the deference between 265.71 and 210. This is shown as 14% effect in Figure 5-9.

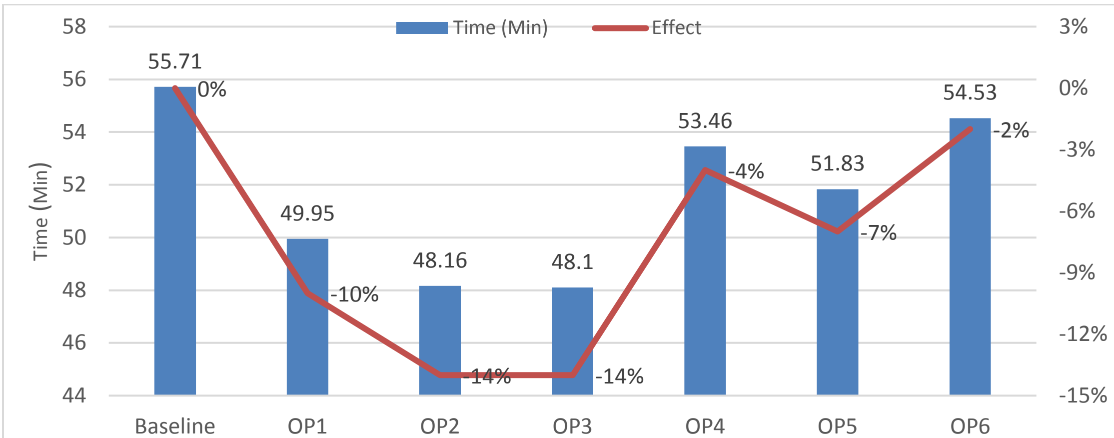

Figure 5-9: Time difference between LOS and dialysis machine working time: Evaluating improvement scenarios

Figure 5-9 shows a great reduction in average of time-difference between LOS and dialysis machine working time by applying staggered start time strategy. Generally, a 14% reduction can be expected by using OP3 for starting at 8:00 AM, 18 patients scheduled. Even with the application of OP3, there is still some space for the system improvement.

5.2.4 Combination of Staggered Start Time Strategy and Float Nurse Strategy

Staggered start time and float nurse strategies showed some level of improvement in KPIs. To further enhance the dialysis unit performance, combining the two methods is considered in this section.

As previously stated, adding one float nurse for put-ons is more desirable and operations 2 and 3 show acceptable results. Therefore, results for the combination of one float nurse with operations 2 and 3 is reported in Table 5-15.

Table 5-15: Results of combination of SST OP2 and OP3 with 1 float nurse for put-on on KPIs

	Baseline	**SST (OP2) and 1FN for Put-on**	**SST (OP3) and 1FN for Put-on**
Within 15 min	50%	69.44%	77.78%
Within 20 min	69.44%	91.67%	94.44%
WTSD (Minutes)	17.45	12.46	12.10
LOS (Minutes)	265.71	255.53	254.09

As Table 5-15 illustrates, the maximum level of improvement in KPIs is now achieved in this study. Analysing results for operation 3 and one float nurse for put-ons together show that almost 95 percentage of times dialysis machines start within 20 minutes. This is the maximum achievable value for this indicator since there are cases for which it takes more than 20 minutes to start the dialysis machine. WTSD indicator shows almost a 6-minutes reduction. To visually observe effects of applying the combination, Figures 5-10 and 5-11 are plotted to compare measures of KPIs with the baseline model performance.

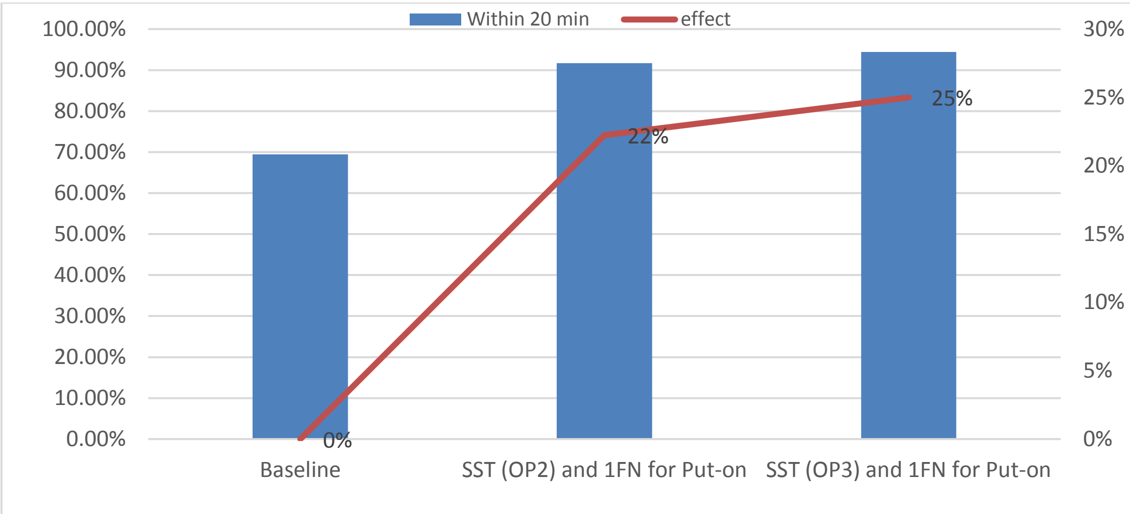

Figure 5-10: Percentage of times dialysis machines start within 20 min: Evaluating improvement scenarios

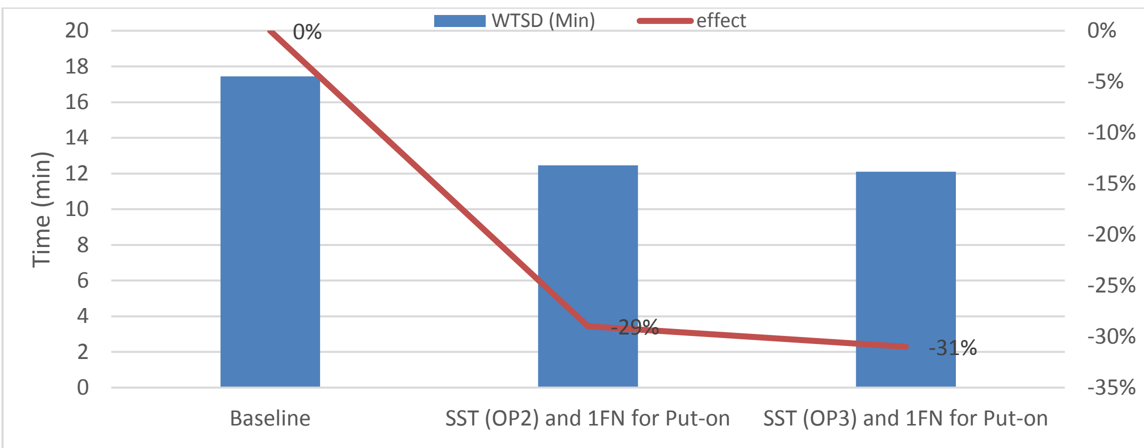

Figure 5-11:Waiting time to start dialysis in evaluating improvement scenarios

As previously discussed, since 210 minutes of LOS time are considered as the dialysis machine’s fixed working time, a 12-minutes reduction in the indicator is achieved out of 55.71 minutes. This is shown as 22% time reduction in Figure 5-12.

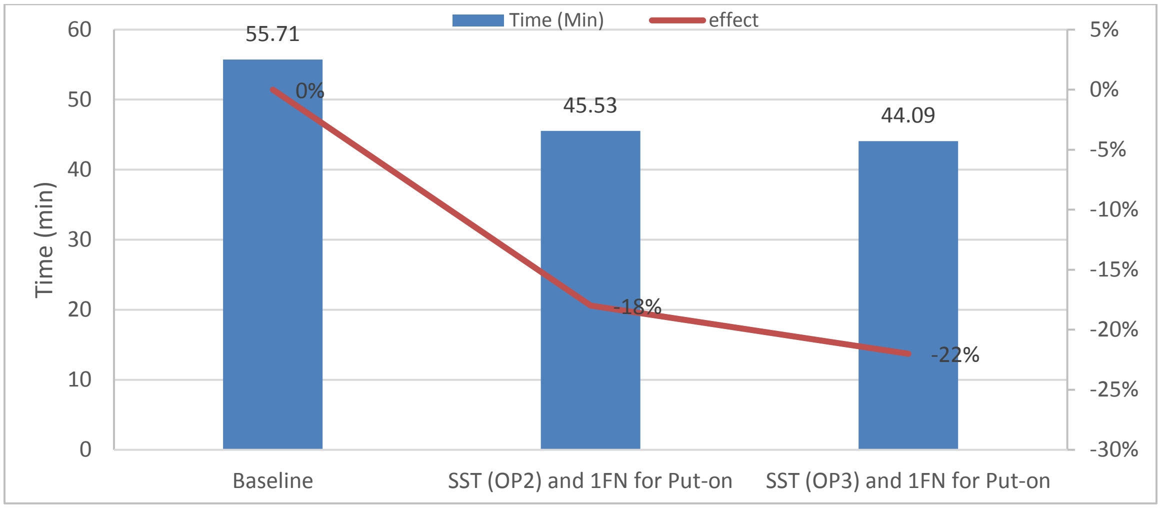

Figure 5-12: Time difference between LOS and dialysis machine working time in evaluating improvement scenarios

In summary, the staggered start time and float nurse strategy are validated alternatives to accelerate the patient flow in HD units at HSC. The model input indicates the combination of adding 1 float nurse to do put-ons and applying staggered start time started at 8:00 am with 18 patients and at 8:30 am with 18 patients (OP3) has significant impact on increment in percentage of times that dialysis machines start within 20 minutes and reduction of waiting time to start dialysis machine (WTSD) and LOS, which improves the HD care delivery efficiency.

Chapter 6

Conclusions and Future Work

6.1 Research Summary

In this research, a discrete-event simulation (DES) model for the existing patient flow in HSC HD units was developed, verified and successfully validated. According to the validated model, operating alternatives were proposed to identify bottlenecks of the HD system. Following key performance indicators (KPIs) were defined to investigate the impact of proposed alternatives in the system.

1. Percentage of times that dialysis machines start within 15 minutes (from patient arrival until the dialysis machine starts),
2. Percentage of times that dialysis machines start within 20 minutes,
3. Wait-Time to Start Dialysis Machine (WTSD) (time duration for patient arrival, weight measurement, initial assessment by a nurse and put-on),
4. Length of stay (LOS) (time interval between patient arrival and departure from the unit).

To achieve a desirable level of system's operation efficiency by improving the predefined KPIs, three strategies were defined as follows:

1. Float Nurse Strategy
2. Changing break times for nurses
3. Staggered Start Time Strategy

Using the simulation model, the influence of these three strategies on KPIs was investigated in comparison with the baseline measures. Increment in percentage of times that dialysis machines start within 20 minutes and reduction of waiting time to start dialysis machine (WTSD) and LOS are the main achievements.

Followings are the main findings of this research:

1. Applying one float nurse only during put-ons showed more effect on the KPIs' improvement.
2. Changing break times for nurses showed insignificant effect on KPIs.
3. The best operation was found among various scenarios for applying staggered start time which was reported as OP3 for starting at 8:00 AM, 18 patients scheduled.
4. The highest level of improvement was achieved for combination of adding one float nurse to put-ons and applying staggered start time based on OP3.

6.2 Research Contributions

Three major contributions are achieved in this research as follows.

1. Proposed various operating alternatives for the HSC HD unit improvement

Operating alternatives were developed in collaboration with the MRP team to achieve an efficient HD system. Simulation modeling was applied as a quantitative approach to provide hospital authorities with a decision-making tool to explore numerous trade-offs between efficiency, workload and capacity.

2. Extended applications of the developed simulation model in HD units

Benefits of simulation modeling in predicting impact of various solutions on HD operation efficiency is explored. Simulation models showed a great capability in determining applications and limitations of novel solutions by providing a means for testing their preliminary findings. Extending staggered start time strategy using simulation can be considered as another contribution achieved in this research study.

3. Contributed to the healthcare advancement

The research results may facilitate WRHA to drive changes to the current HD patients' scheduling.

6.3 Future Research

For the future research, the simulation model can be applied to HD units of other hospitals. This will test the model's applicability to find more items to be added to the model based on other hospital's HD processes. One of these additions could be including transport services for dialysis patients in the model as a further level of details for patient's scheduling. In fact, this could increase the accuracy of the model. The developed model can be further expanded by considering alternative patient transit options since they impact patient time on dialysis and scheduling processes.

Moreover, based on the level of CKD, patients in the MRP Renal Health Clinics are classified. This classification defines types of treatment and scheduling. However, in HD units, there is not an established or standardized form of the patient classification. Individual patient information is held in the Kardex system and varies based on individuals' needs such as the type of access used, mobility, and amount of time required for dialysis. In fact, HD lacks an identification/classification of individual patients by needs, or severity of illness. As a result, this variance affects workflow processes and patient's time in the HD. Moreover, there are increasing problems as the lack of the patient classification for accountability and scheduling. For example, various forms of the mobility define whether the patient requires the Hoyer, or if dialyzing from a chair is more appropriate and beneficial than a bed. The use of a Hoyer requires extra staff and time to weigh and lift the patient to the bed. A patient classification would identify scheduling issues and assignment to a location, bed, or chair. This has led to increased pressure on the existing facility and long wait-times. Therefore, following possible directions are suggested for the further research. Development of a patient classification method for patient requirements that can be tracked and/or monitored, as well as identifying and measuring tools for workload, and to justify staffing mix and resource levels needed.

In addition, there are number of legacy systems in HD units but none of them integrate information such as IPN, paper book, case summary, dietitians' book or Kardex. As a result, to further improve the operation efficiency of the system, implementation of electronic patient health records to improve communication and information sharing amongst the team should be considered.

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Appendix A: Time Study

Hemodialysis – Time Study **Surveyor's Name**______________________

Please check the appropriate response and provide additional feedback where requested. (All time is recorded using 24-hour clock)

Arrival Information
Today's Date: DD/MM/YY
Patient mode of arrival: *(check one only)* Self ☐ Private Service ☐ Taxi ☐ Handi-Transit ☐ Other ____________
Patient arrival time at the door: HH: MM
Time patient leaves Wait Room for Hemodialysis Unit: HH: MM
Patient Demographics
Patient Status: *(check all that apply)* Ambulatory ☐ Wheelchair ☐ Stretcher☐ Outpatient ☐ Inpatient ☐ Amputations: Yes ☐ No ☐
Regular scheduled dialysis treatment: Yes ☐ No ☐ Did not arrive ☐

Assigned patient station number if known: # ☐☐
Scheduled Cycle time (hours): 3☐ 3.5 ☐ 4 ☐ 4.5 ☐ 5 ☐
Assessment
Time patient arrives in Hemodialysis Unit: HH: MM
Time patient is weighed: start HH: MM
Time patient arrives at bed / chair: start HH: MM
Hoyer needed: Yes ☐ No ☐ Time on Hoyer: start HH: MM stop HH: MM
Nurse Assessment: start HH: MM stop HH: MM
Type of access: Central Line ☐ or AVF: Regular Access☐Buttonhole Self ☐ Buttonhole N ☐
Access central line or AVF : start HH: MM stop HH: MM
Treatment
Personal Health Identification Number : ☐ ☐ ☐ / ☐ ☐ ☐ / ☐ ☐ ☐
Time patient starts dialysis: start HH: MM
Interventions (1): start HH: MM stop HH: MM Comments ____
Interventions (2): start HH: MM stop HH: MM

Comments ____
Interventions (3): start HH: MM stop HH: MM
Wound Care: start HH: MM stop HH: MM
Time patient ends treatment (rinse-back complete): stop HH: MM
If Antibiotics needed: start HH: MM stop HH: MM
Time Care Provider extends visit (example, the time spent with Physician, Pharmacist, Dietitian, Nurse) : start HH: MM stop HH: MM
Time Nurse does post dialysis check (blood pressure, dressings, etc.) start HH: MM stop HH: MM
Hoyer needed: Yes ☐ No ☐ Time on Hoyer: start HH: MM stop HH: MM
Discharge
Time HCA assists patient to dress and weigh start HH: MM stop HH: MM
Time patient is taken to wait room (exit HD unit): HH: MM
Time patient departs: HH: MM

Appendix B: Distribution Data

Access			Service Time (Minutes)
ACC1	3 punctures fistula	3.48%	23
ACC2	CVC switching mid Tx line	4.00%	5
ACC3	> 3 punctures	0.00%	-
ACC4	rTPA dwell	0.71%	4
ACC5	rTPA push line	0.00%	-
ACC6	rTPA push and dwell	0.00%	-
ACC7	Occlusive CVC dressing/Temporary CVC line	23.19%	5
ACC8	Unable to hold AVF sites post HD	4.43%	20
ACC9	Baseline	64.19	7
Monitoring			Service Time (Minutes)
MON1	V/S required q15x1-1.5 hours	16.76%	6
MON2	V/S required q15 >1.5 hours	10.57%	16
MON3	O2 sat monitor used	5.86%	1
MON4	Blood glucose monitoring	56.52%	6
MON5	Baseline	10.29%	2
Elimination			Service Time (Minutes)
ELI1	Incontinent of stool/Ostomy care required	3.05%	10
ELI2	Baseline	96.95%	5
Isolation Precautions			Service Time (Minutes)
ISO1	Any isolation	14.05%	16
ISO2	TB	0.00%	-
ISO3	Bed bugs	0.71%	24
ISO4	Baseline	85.24%	7
Complications			Service Time (Minutes)
COM1	Cramping	13.81%	2
COM2	Intervention for hypotension/hypertension	11.48%	3
COM3	Chest pain/arrhythmia	0.81%	20
COM4	Baseline	73.90%	5
Treatments			Service Time

			(Minutes)
TRE1	Wound care/dressing change <15 min	10.38%	4
TRE2	Wound care/dressing change 15 - 30 min	2.43%	20
TRE3	Wound care/dressing change >30 min	0.71%	35
TRE4	Foot assessment req'd > q3mth	11.95%	3
TRE5	Dialyzer clotted/new set up	1.29%	6
TRE6	Recirculation bloodwork	3.52%	2
TRE7	IV antibiotic	9.95%	2
TRE8	IV iron loading dose	3.95%	2
TRE9	Continuous infusion from ward	1.00%	2
TRE10	Bloodwork other than routine monthly	18.19%	1
TRE11	Blood product administration	0.00%	-
TRE12	Medications po/sc/routine iv	36.63%	0.5
TRE13	CPAP during HD	0.00%	-
Education/Communication			Service Time (Minutes)
EDU1	Issue for nephrologist	16.38%	2
EDU2	Aggressive/violent/challenging behaviour	0.00%	-
EDU3	Communication barrier	0.00%	-
EDU4	Confusion	0.00%	-
EDU5	Restraints in use	0.00%	-
EDU6	Emotional support - occasional	0.00%	-
EDU7	Emotional support - frequent	0.00%	-
EDU8	Patient Education (repeated)	5.57%	6